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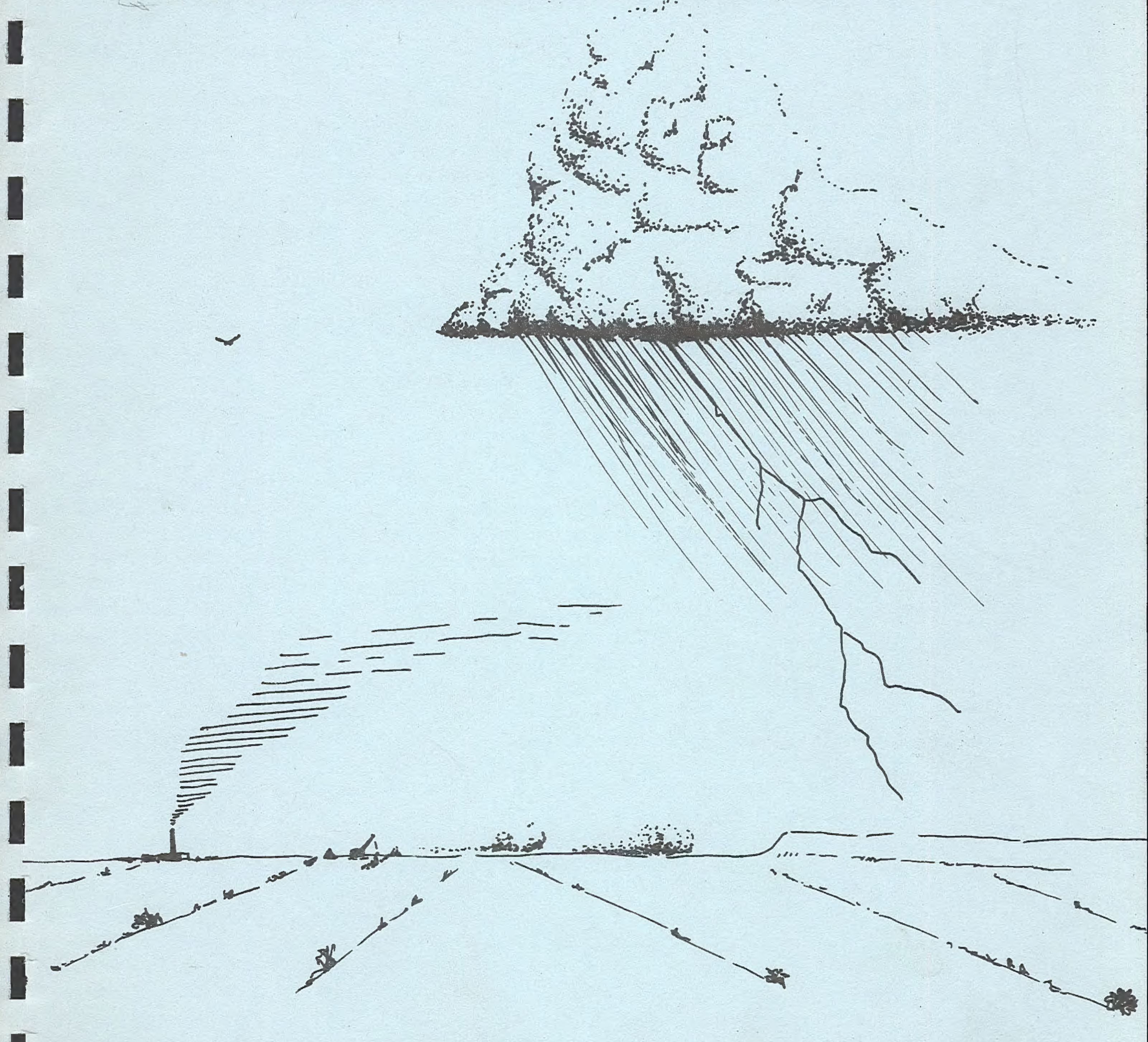

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CLIMATE AND AIR QUALITY

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TO THE
WEST-CENTRAL NORTH DAKOTA
REGIONAL ENVIRONMENTAL IMPACT STUDY

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Prepared by the Division of Environmental Engineering of the North Dakota State Department of Health, Gene A. Christianson, P.E., Director, in cooperation with the U.S. Department of Interior, Bureau of Land Management, and the Natural Resources Council of the State of North Dakota.

December 1977

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PREFACE

This document has been prepared to supplement information contained in the West-Central North Dakota Regional Environmental Impact Study on Energy Development. Where feasible, data supportive of the study were included in the body of the study document itself in the form of appendices. However, in the case of the Climate and Air Quality, Economic and Social Conditions, and Land Use components, additional supportive methodological data in the form of Technical Supplements were deemed desirable. These Technical Supplements provide additional information for the reader who wishes to examine a particular environmental component in greater detail than is available in either the summary document or the study document itself.

In addition, a Technical Report describing Coal Related Impacts to the Ft. Berthold Reservation has been prepared. This document, prepared at the request of the North Dakota Indian Affairs Commission, examines the impact of proposed energy developments upon the Ft. Berthold Reservation exclusively.

Copies of:

Climate and Air Quality Technical Supplement
Economic and Social Conditions Technical Supplement
Land Use Technical Supplement and
Coal Related Impacts to the Ft. Berthold Reservation

are available on request from:

Regional EIS Office
1533 North 12th Street
Bismarck, ND 58505

BLM District Office
DSC, Pulver Hall, Box 1229
Dickinson, ND 58601

BLM, Montana State Office
PO Box 30157
Billings, MT 59107

ABSTRACT

This report is a compilation of the supportive technical information which provided the background data and information utilized in the draft of the Climate and Air Quality sections of the joint Federal-State Regional Environmental Impact Study of proposed energy developments in a seven county area of western North Dakota. The technical information and data are presented as four individual sections of this report. A key word index of available technical information is provided as a guide to the reader of the regional study document to facilitate access to information of interest.

The four sections of this report include: An Air Pollution Climatology Report for the Seven County Study Area, An Air Quality Assessment of Proposed Energy Developments in the seven county study area, a report prepared by the North Dakota State Department of Health for the Old West Regional Commission on the Trace Element Effects of Energy Conversion Facilities, and a report prepared by the North Dakota State Department of Health for the Bureau of Land Management on the Determination of Particulate Emission Factors From Lignite Mining Operations.

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AN AIR POLLUTION CLIMATOLOGY
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IN WESTERN NORTH DAKOTA

AN AIR POLLUTION CLIMATOLOGY OF A SEVEN COUNTY AREA IN WESTERN NORTH DAKOTA

A FINAL REPORT
COOPERATIVE AGREEMENT
PROJECT NO. 2520-513-5120

by

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to

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Climatic Data Laboratory
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North Dakota State University
Fargo, North Dakota

October 30, 1976

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PREFACE

This is the final report of a four-month research study conducted at the Department of Soils under a Cooperative Agreement with the North Dakota State Health Department; Project No. 2520-513-5120.

The report includes computer print-outs and computer card decks of meteorological parameters for convenient use in short-term and long-term dispersion modeling using existing UNAMAP models from the U.S. Environmental Protection Agency.

ACKNOWLEDGEMENTS

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J. M. Ramirez
T. Method

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CHAPTER I

A CLIMATOLOGICAL DESCRIPTION OF THE EXISTING ENVIRONMENT

THE STUDY AREA

The study site comprises seven adjoining counties in west central and south central North Dakota, namely; Burleigh, Morton, Stark, Oliver, Mercer, Mclean, and Dunn. The location of these counties relative to the entire state of North Dakota is shown in Figure 1. This geographic region has a continental climate. It has a large range of both annual and diurnal temperatures. The mean daily minimum temperatures in Dickinson, for example, range from -1^{o}F in January to 54^{o}F in July and August; while the record extremes are a minimum of -42^{o}F and a maximum of 109^{o}F.

The Rocky Mountains to the far West of the study area act as a barrier which modifies the prevailing westerly flow but no significant physical barriers exist to affect the cold air masses from the North or the warm and relatively more moist air masses from the Gulf of Mexico. The area is generally characterized by light to moderate precipitation which tends to be irregular in time and coverage of occurrence, low relative humidity and nearly continuous air movement.

Normally, there is a rapid progression of air masses originating from the polar regions, the Gulf of Mexico and on occasions, from the Northern Pacific. The cold, dry air masses from the North intensify the areas winters while the warm, relatively moist air from the South dictate most of its precipitation characteristics.

The seven-county area is generally classified as semi-arid with annual precipitation ranging from 16 to 18 inches.

Data Sources

There are 30 National Weather Service (NWS) Cooperative Weather Substations in the seven-county study area. A review and assessment of the quality, length and completeness of climatic records for these stations were made and only 20 stations were selected for use as data points in this study. In addition, however, the complete data from 13 additional stations in the surrounding counties were also analyzed for continuity in the areal analyses of climatic elements. The locations of the 43 stations are shown in Figure 2 and a summary of the extent and completeness of the climatic record is given in Table 1.

In addition to surface climatic data from the NWS substations, supporting data from meteorological towers in Stanton, Dickinson, and Dunn Center for limited periods of time were referred to. These data files were gathered by a North Dakota State University team of scientists for other studies and are made available for this present report.

Specialized data on hourly and 3-hourly records of wind profiles for Bismarck, Dickinson, Minot and Williston for a 20-year period were obtained from the National Climatic Center for the stability class analyses over the region. Additional data from the efforts of the Northern Great Plains Resource Program (NGPRP) in North Dakota were

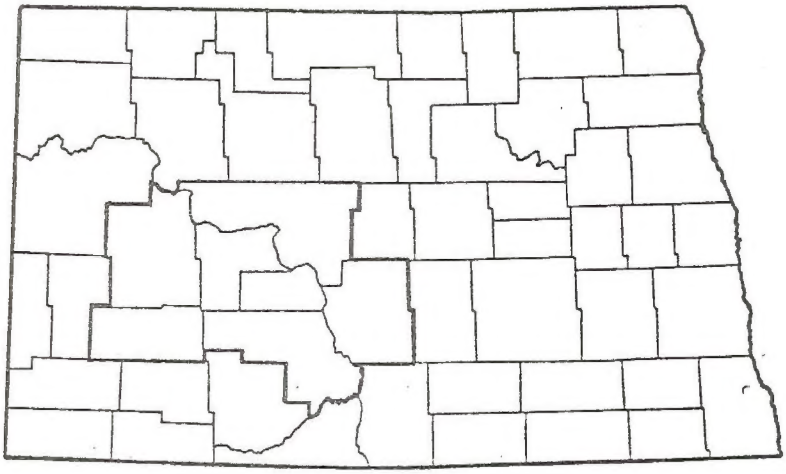


Figure 1. The Location of Seven-County Study Area in North Dakota

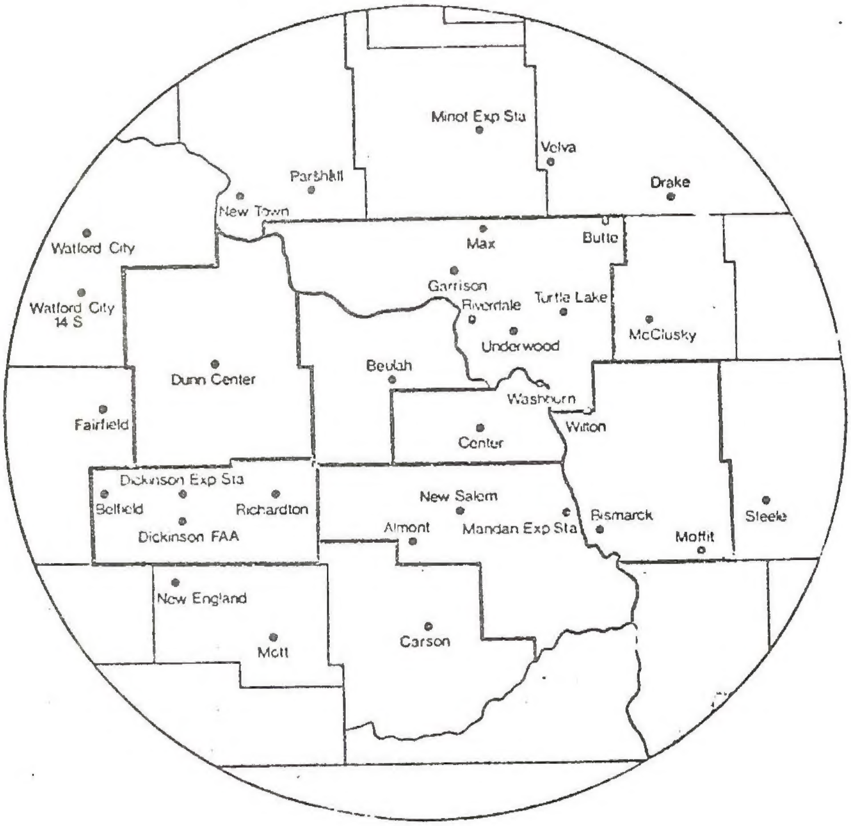


Figure 2. The Locations of the Weather Stations for which Long Term Data were used in the Climatic Analyses

TABLE 1 CLIMATIC STATIONS IN WESTERN NORTH DAKOTA USED IN THE CLIMATOLOGICAL ANALYSES AND THE EXTENT, QUALITY AND COMPLETENESS OF RECORDS

				Climatic elements included (percent of total)					
Station	Period Covered	Years	% Missing Date	T.Mx.	T.Mn.	Prec.	24 hr. Snow	Snow Depth.	Evap. Apr.-Oct.
Almont	48-74	26	16	100	100	100	97	94	0
Belfield	48-74	26	0	99	99	99	88	90	0
Beulah	48-74	26	0	77	77	100	92	88	0
Bismarck	48-74	26	0	100	100	100	100	100	0
Butte	48-74	26	4	92	92	97	86	83	0
Carson #2	14-74	60	2	100	100	100	100	99	0
Center	48-74	26	0	99	98	100	100	99	0
Dickinson Exp	03-74	71	0	100	100	100	97	98	37
Dickinson Faa	48-74	26	0	100	100	100	100	100	0
Drake	48-74	26	0	99	99	100	78	83	0
Dunn Center	18-74	56	0	97	97	100	100	100	0
Fairfield	48-74	26	2	73	73	100	100	93	0
Garrison	11-74	63	0	98	98	98	96	95	0
Mandan Exp	13-74	61	0	99	99	99	100	100	52
Max	48-74	26	4	98	98	99	99	91	0
McClusky	18-74	56	1	100	100	100	100	97	0
Minot Exp	05-74	69	0	100	100	100	99	99	0
Moffit	48-74	26	6	77	77	100	99	96	0
Mott	48-74	26	0	99	99	100	93	98	0
New England	48-74	26	0	100	100	100	95	88	0
New Salem	48-74	26	0	99	99	99	99	87	0
Newtown	52-74	22	1	96	96	97	95	92	0
Parshall	15-74	59	0	100	100	100	100	99	0
Richardton	48-74	26	1	100	100	100	100	98	0
Riverdale	48-74	26	0	99	99	100	91	95	80
Steele	48-74	26	0	99	99	100	99	98	0
Turtle Lake	48-74	26	0	96	96	97	80	75	0
Underwood	54-74	20	0	99	99	100	94	96	0
Velva	48-74	26	0	100	100	99	99	98	0
Washburn	31-74	43	0	97	96	97	97	95	0
Watford City	36-74	38	0	97	97	97	96	96	0
Watford City 14S	51-74	23	5	95	95	99	92	95	0
Wilton	48-74	26	1	90	89	94	90	70	0

also obtained from the National Environmental Protection Agency Region VIII Office in Denver, Colorado.

AIR TEMPERATURES

The mean annual temperatures across the seven-county area is shown in Figure 3 to range between 39°F and 43°F. A more meaningful picture of the temperature climatology in the area is given in Figure 4 which shows the monthly values as well as the normal maximum and minimum readings for three selected station locations in the region. While the monthly temperature normals in the region range from 4°F to 70°F; the mean daily extreme temperatures show normal minimas from about -2°F in January and normal maximas of around 83°F in July.

Freeze-free period

Across the study area, the first freeze in the fall is expected in mid-September, while the mean date of the last freeze in the spring is around May 20 (Table 2). Normally, the minimum daily temperatures in the area dip below freezing on 228 to 248 days of the year. The distribution of lengths of the frost-free period in the region is shown in Figure 5.

Freezing Temperatures in the Spring and Fall

The occurrence of frost (32°F or below) affects the planning and operation scheduling of some outdoor activities in agriculture, recreation and construction. The probabilities of the occurrence of frost in the

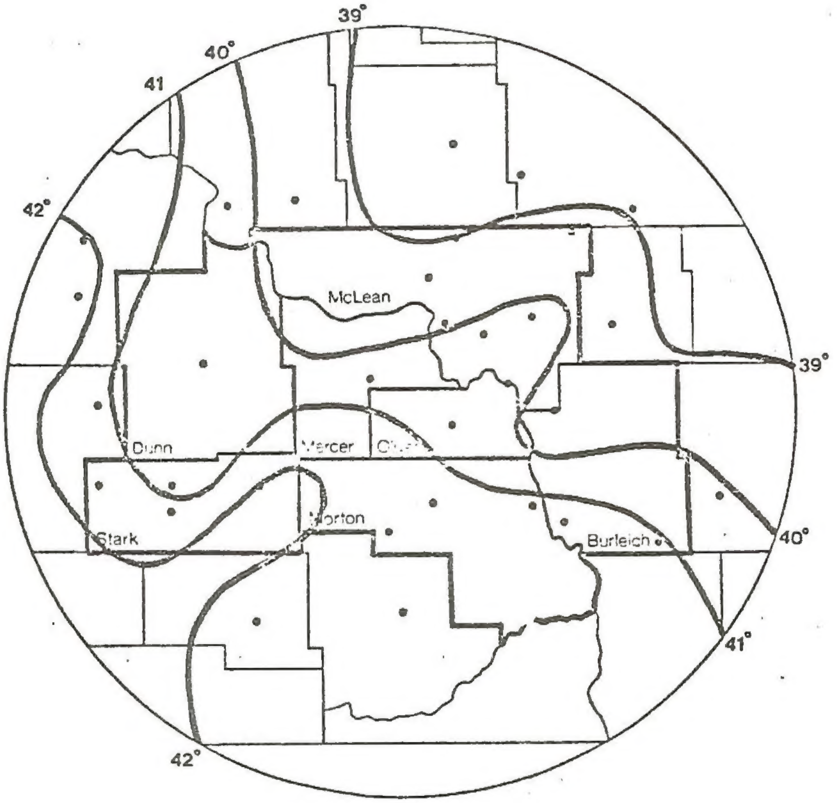


Figure 3. The Mean Annual Temperatures in °F Across the Study Area (1941 - 1970)

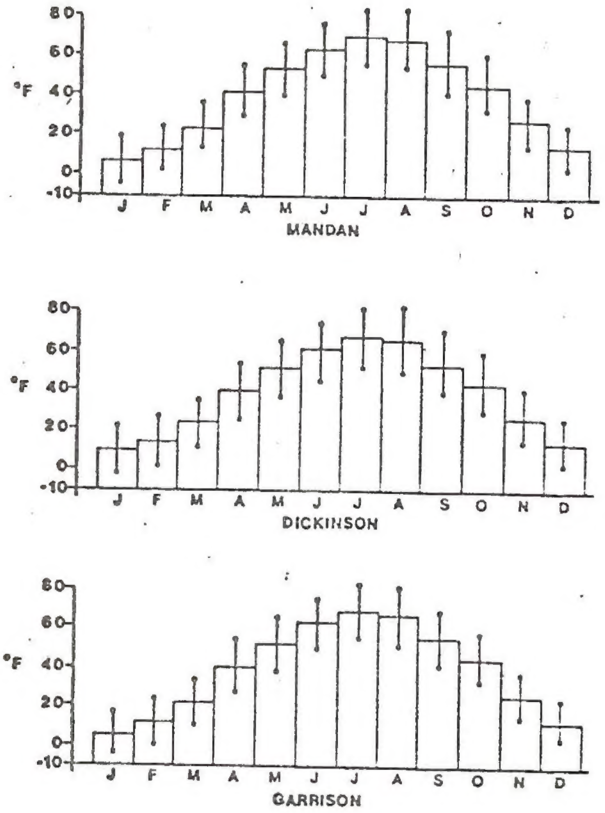


Figure 4. The Monthly Normal Mean Maximum and Mean Minimum Temperatures (1941-1970) at Three Selected Stations in the Study Area

TABLE 2 THE MEAN DATES OF THE FIRST AND THE LAST FROSTS (TEMPERATURES $\leq$ 32°F) IN THE STUDY AREA

STATION	DATE OF FIRST FREEZE	MEAN DATE OF LAST FREEZE	YEARS OF RECORD
Almont	May 10	September 27	48-74
Belfield	May 17	September 18	48-74
Beulah	May 17	September 15	48-74
Bismarck	May 13	September 23	48-74
Butte	May 17	September 24	48-74
Carson #2	May 19	September 15	14-74
Center	May 20	September 14	48-74
Dickinson Exp	May 19	September 14	03-74
Dickinson Faa	May 12	September 23	48-74
Drake	May 16	September 20	48-74
Dunn Center	May 17	September 18	18-74
Fairfield	May 13	September 23	48-74
Garrison	May 18	September 19	11-74
Mandan Exp	May 12	September 23	13-74
Max	May 14	September 18	48-74
McClusky	May 20	September 18	18-74
Minot Exp	May 20	September 17	05-74
Moffit	May 22	September 18	48-74
Mott	May 18	September 13	48-74
New England	May 17	September 16	48-74
New Salem	May 16	September 22	48-74
Newtown	May 15	September 14	52-74
Parshall	May 21	September 12	15-74
Richardton	May 14	September 24	48-74
Riverdale	May 13	September 25	48-74
Steele	May 13	September 23	48-74
Turtle Lake	May 14	September 23	48-74
Underwood	May 14	September 20	54-74
Velva	May 18	September 17	48-74
Washburn	May 13	September 24	31-74
Watford City	May 13	September 19	36-74
Watford City 14S	May 16	September 13	51-74
Wilton	May 13	September 23	48-74

study area are shown in Table 3. Even as late as early May, the chances are that in 8 out of 10 years a frost will occur in the study area. In the fall, frost can occur with the same probability as early as the last week of September.

TABLE 3. PROBABILITIES OF FREEZING TEMPERATURES IN SPRING AND FALL IN THE STUDY AREA

WEEK	PROBABILITY RANGE Southeastern Half	 Northwestern Half
Spring:		
May 3-9	75-80%	80-85%
May 17-23	35-40%	40-45%
May 31-June 6	5-10%	10-15%
Fall:		
Aug. 30-Sept. 5	5-10%	10-15%
September 13-19	40-45%	45-50%
Sept. 27-Oct. 3	75-80%	80-85%

Extreme High Temperatures

The persistence of high temperatures are good indicators of rapid evaporative losses from cooling ponds and other surfaces and of uncomfortable conditions for outdoor labor. The number of days per year when maximum temperatures exceed 90°F is a fair index of the persistence of high daily temperatures. In an earlier study, these conditions have also been shown to be negatively correlated to small grain yields in North Dakota. In the study area, there are days when the daily maximum temperatures exceeded 90°F. Its distribution across the region is shown in Figure 6. In the hottest weeks of the year in late-July and

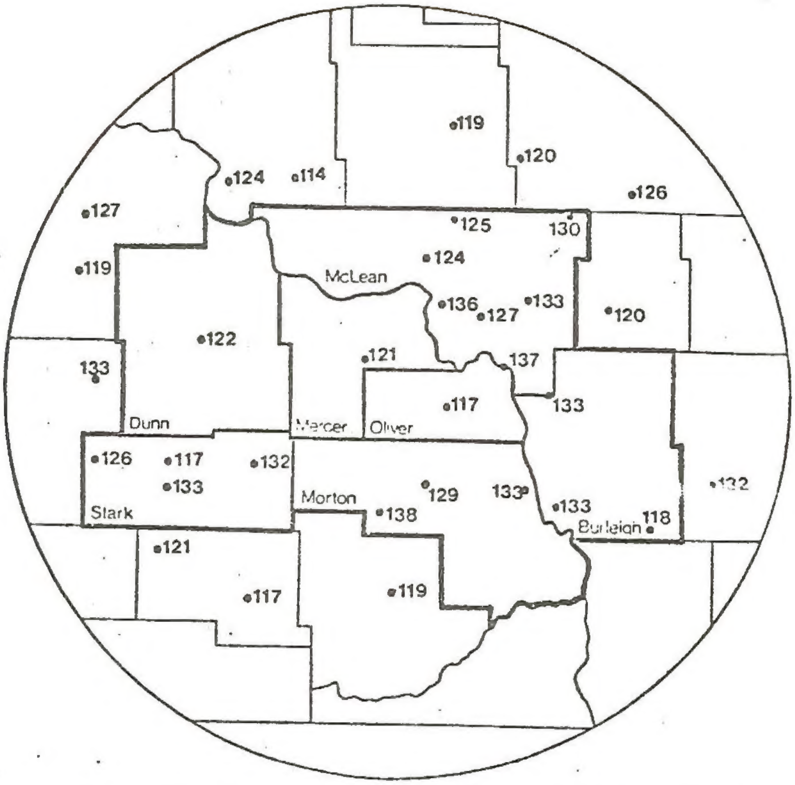


Figure 5. The Mean Annual Number of Frost-Free Days at Different Locations Across the Study Area

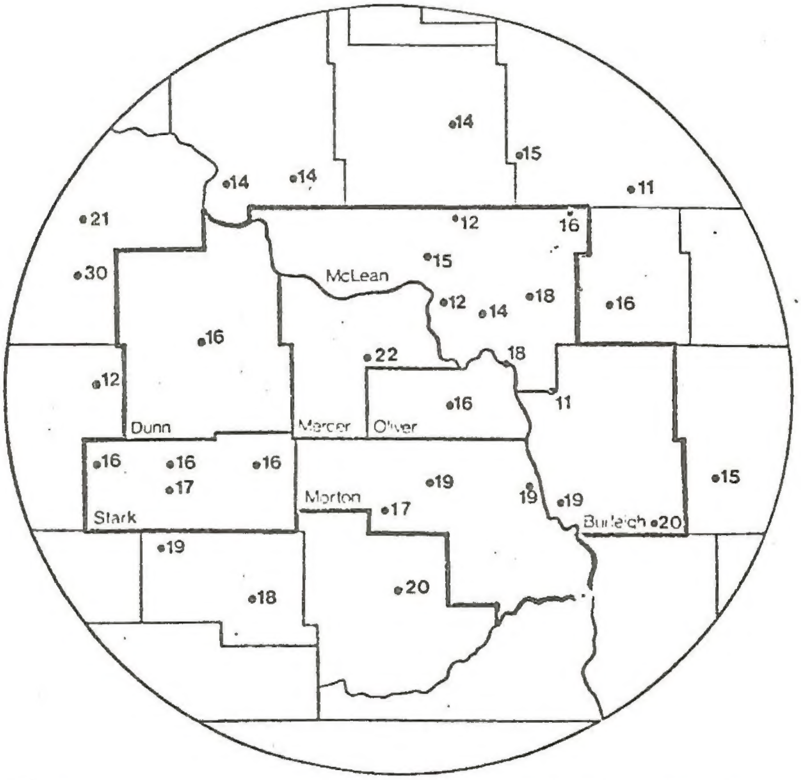


Figure 6. The Mean Annual Number of Days When Maximum Temperatures are Equal or Greater Than 90^{O}F at Selected Locations in the Study Area

mid-August, at least one occurrence of 90°F and above is expected in at least 8 of every 10 years in the area.

Winter Temperatures

Sub-zero temperatures. The frequencies of temperatures below zero serve as useful indicators of extreme cold. Especially when sub-zero cold temperatures occur with high winds, livestock must be given special protection and all outdoor activities are further limited unless adequate shelter and clothing protections are prepared in advance. Temperatures below zero occurring for five days in a row may be expected across the study area from about the first week of December with probabilities of 5 to 10%, through the last week of February when the chances of occurrence are about 20%. Through the winter, the probabilities of such cold conditions occurring are summarized in Table 4.

TABLE 4 PROBABILITIES OF SUB-ZERO TEMPERATURES FOR FIVE DAYS IN A ROW IN THE STUDY AREA

WEEK	PROBABILITY RANGE
December 13-19	20-30%
December 27-January 2	25-30%
January 10-16	35-40%
January 24-30	40-45%
February 7-13	25-30%
February 21-29	20-25%

Above Freezing Temperatures in the Winter. The extended occurrences of temperatures above freezing during the winter months in Western North Dakota lend some significance to the proper planning and completion of outdoor work such as those in construction. The frequencies of these conditions are also important considerations in spring flood forecasting as they are related to the rates at which snow cover amounts are evaporated or sublimated. Across the study area, a five-day run of temperatures above 32°F occur less than 50% of the time in late November through the first week in March. The range of these probabilities through the winter in the region is given in Table 5.

TABLE 5 PROBABILITIES OF ABOVE-FREEZING TEMPERATURES FOR FIVE DAYS IN A ROW DURING THE WINTER IN THE STUDY AREA

WEEK	PROBABILITY RANGE
November 8-14	60-65%
December 6-12	25-30%
January 3-9	5-15%
January 31-February 6	15-25%
March 1-7	25-35%
March 29-April 4	85-90%

Degree Days

The arithmetic accumulations of mean daily temperatures above or below a certain threshold value have been used as a convenient means of relating air temperatures to plant growth and development, cooling requirements in the summer, and heating requirements in the winter. For these applications, the accumulated heat units are referred to as growing degree days, heating degree days and cooling degree days, respectively.

The National Weather Service reasonably assumes that most households and business establishments usually turn their heaters on when temperatures dip below 65°F. The negative departures of the daily temperatures from 65°F is calculated by the NWS and is termed heating-degree days (HDD). Similarly, the energy requirements for air conditioning in the summer are estimated from the accumulated positive departures from 65°F and are labelled cooling-degree days (CDD).

The monthly distribution of the annual number of HDD and CDD across the study area is given in Table 6 for selected stations.

PRECIPITATION

The annual totals of precipitation for each station in the study area range from about 16 to 18 inches (Figure 7), increasing in a general easterly direction. Despite this relatively low amount of precipitation, the area's rangeland and agriculture obtain most of their moisture needs from the non-winter (April through September) precipitation which comprises over 80% of the total. As in most of the Upper Midwest, rainfall in the spring is usually light, increasing until late June and then gradually decreasing towards the winter months. The monthly normals and the record extremes of precipitation in three selected stations is in Figure 8.

TABLE 6 THE MONTHLY AND ANNUAL NORMALS OF HEATING AND COOLING DEGREE DAYS IN SELECTED LOCATIONS IN THE STUDY AREA

MONTHS	STATIONS					
	Bismarck	New Salem	Dickinson	Center	Dunn Center	Turtle Lake
HEATING DEGREE DAYS						
January	1761	1711	1693	1752	1730	1783
February	1442	1403	1397	1431	1420	1473
March	1237	1243	1265	1268	1293	1280
April	660	693	726	708	735	687
May	339	363	404	370	403	350
June	122	139	165	142	167	129
July	18	25	31	23	35	28
August	35	41	50	47	67	37
September	252	257	299	286	308	257
October	564	564	614	598	611	567
November	1083	1083	1098	1098	1104	1107
December	1531	1494	1485	1535	1510	1556
Annual	9044	9016	9227	9258	9383	9254
COOLING DEGREE DAYS						
May	11	66	7	7	7	9
June	86	67	48	61	56	72
July	198	177	139	147	147	177
August	165	156	128	128	135	155
September	27	29	23	16	23	26
Annual	487	442	345	359	368	439

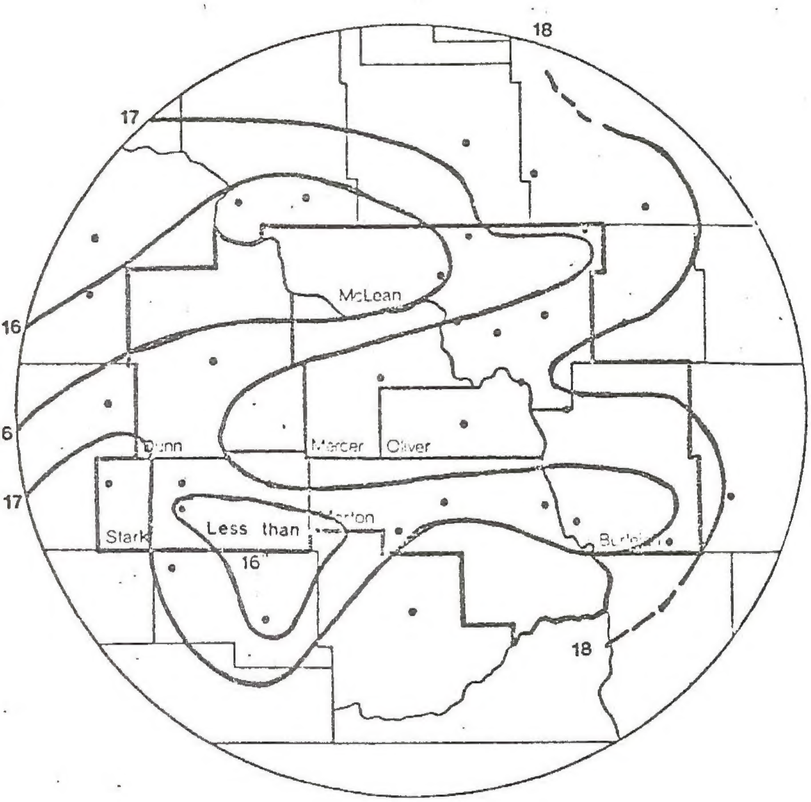


Figure 7. Mean Annual Precipitation in Inches Across the Study Area

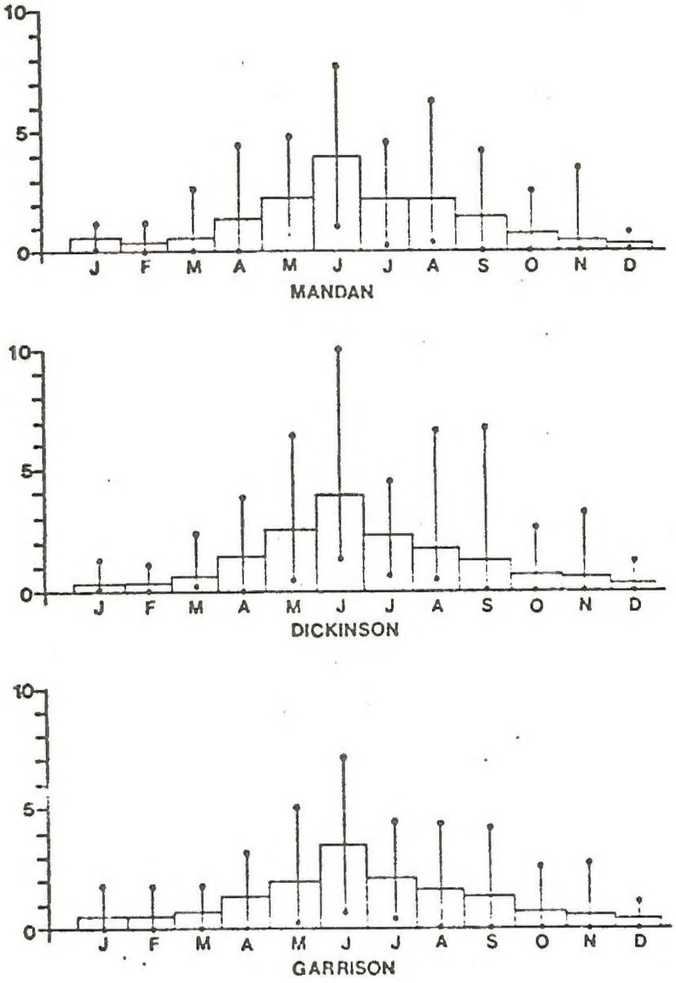


Figure 8. The Normal and Recorded Extremes of Monthly Precipitations at Three Selected Stations in the Study Area

The weekly totals of precipitation in the seven-county area gradually increases from less than a tenth of an inch in the winter months to about three-tenths of a inch in mid-April and then it increases more rapidly up to a little less than one inch in late June. After the normally maximum rainfall in late June, the weekly totals decrease gradually to less than a tenth of an inch. Using an Incomplete Gamma Function fit on the weekly totals of rainfall, the probabilities of receiving at least one, 0.6 and 0.1 inch of rain at three selected stations in the area are shown in Figure 9. Even in the rainiest weeks of June in the area, the chances for receiving, one week, a total of one inch is just about one out of every three years.

Snow

The mean snowfall across the study area is displayed in Figure 10. In equivalent melted amounts, these snow totals are about one-fourth of the annual precipitation total in the area. The monthly distribution of these totals for Dickinson, Garrison and Mandan is shown in Figure 11. According to Jensen (1972), the accumulated snow depths in the area will be an inch or more in 90 to 110 days, six inches or more in 30 to 45 days, and 18 inches accumulation in only 1 to 4 days of the year. In Stark county, the first inch accumulation of snow is expected around December 20. While the mean date for the more northern counties of Maclean, Mercer and Oliver is between December 5 and 10. The last inch of snow-on-the-ground in the area occurs around a mean date of March 20.

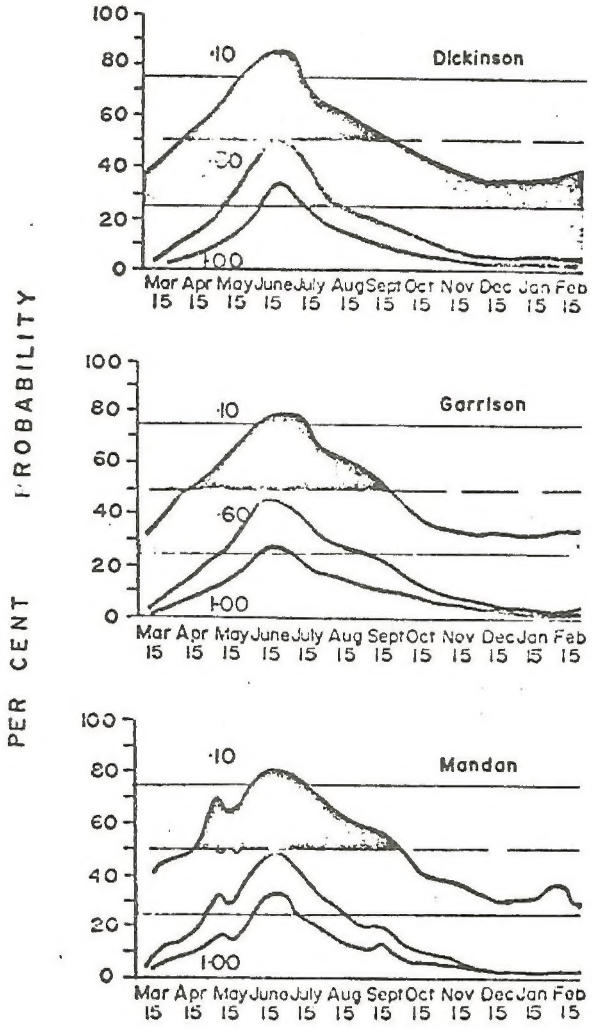


Figure 9. The Probabilities of Receiving Selected Amounts of Precipitation Per Week at Three Selected Locations in the Study Area

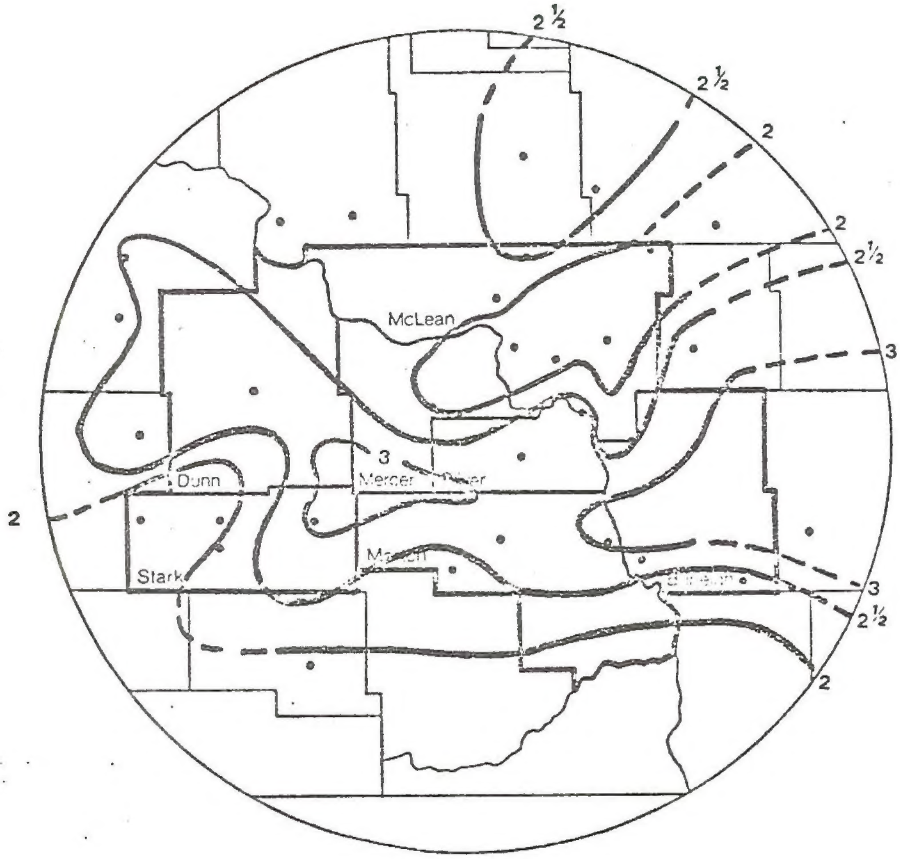


Figure 10. Mean Annual Snowfall in Feet Across the Study Area (1941 - 1970)

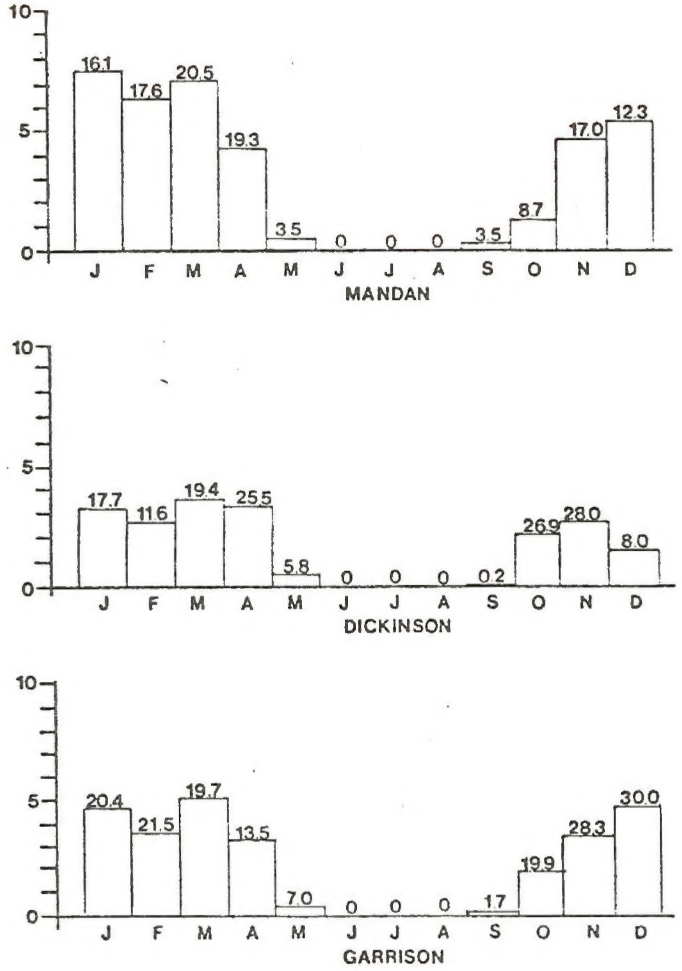


Figure 11. The Monthly Normal and Extremes of Snowfall at Three Selected Locations in the Study Area (Inches; the number above each bar indicate maximum amount ever recorded)

Approximately 10 to 14 inches of snowfall in the seven-county region make one inch of melted water equivalent (Ramirez, 1973). The snow has the least melted water equivalents in the mid-winter months of November through early March and becomes wetter towards spring.

SEVERE STORMS

As in the entire State of North Dakota, a major portion of the growing season rainfall in the study area is associated with thunderstorms. From 30 years of record in Bismarck, the mean number of thunderstorm days in the area is 36, mostly occurring in the period between April through October. Its monthly distribution through this period shows that the frequencies are highest in June (10 thunderstorm days) and least in April and October (average of 1 thunderstorm per month).

Hail

An updated hail climatology summary for North Dakota is largely absent. Using 20 years of climatic record ending in 1962, Changnon (1962) showed the distribution of the total number of hail days, over a twenty year period in the north-central states. The portion of his map corresponding to the study area is shown in Figure 12. Over twenty years, 40 to 60 days with damaging hail have been reported in the study area. July is the major hail month in the area, followed by June and then August.

Tornadoes

Tornadoes are rare in North Dakota, but their occurrence is a real possibility at any location in the State including the seven-county study area. The records between 1940-1970 in the region show that between one to three tornadoe events have been reported in each of the seven counties. This statistic, however, is questionable because of the large expanse of sparsely populated range and farms in the area where twisters can touch down unnoticed. The point must be established, however, that tornadoes are a possible threat in the region especially in the months of late June, July and August.

SUNSHINE AND CLOUDINESS

Approximately 60% of the total possible sunshine over the entire year is incident on the study area. The monthly distribution of the percent of maximum possible sunshine for Bismarck (which is the only station in the area presently recording sunshine and radiation data) is shown in Table 8. The sunniest months are July and August and the cloudiest are November and December.

A more direct measure of the solar energy received on a horizontal surface is that obtained using a pyronometer, such as one exposed at the Bismarck airport station. The mean total calories per/cm^2 (langley) received per day for each month of the year is also given in Table 8. Around 600 langleys per day are received in solstice month of June, while only about 124 langleys per day are incident on the average during the short days of December.

TABLE 8. THE AVERAGE PERCENT OF MAXIMUM POSSIBLE SUNSHINE AND MEAN DAILY SOLAR RADIATION IN BISMARCK*

MONTH	PERCENT OF MAXIMUM POSSIBLE SUNSHINE	SOLAR RADIATION LANGLEYS PER DAY
January	52	157
February	58	250
March	56	356
April	57	447
May	58	550
June	61	590
July	73	617
August	69	516
September	62	390
October	59	272
November	49	161
December	48	124
Annual Mean	59	369

*The % of possible sunshine data is from records between 1931-1960, Solar Radiation data is averaged from records between 6 to 11 years in length, between 1948 to 1960.

In the general vicinities of the study area and as represented by the Bismarck station, about 45% of the days of the year have 80 to 100% cloud cover, generally termed as cloudy by the National Weather Service. About 25% of the days are clear (0 to 30% cloud cover). The more cloudy days occur in the late fall through early spring during which there are 5 to 7 days of each month when the skies have less than 30% of cloud cover. Relatively, July and August have about twice as many days of clear skies (Table 9).

TABLE 9 AVERAGE NUMBER OF CLEAR (C), PARTLY CLEAR (PC), AND CLOUDY (CY) DAYS IN BISMARCK*

MONTH	NUMBER OF CLEAR DAYS	NUMBER OF PARTLY CLOUDY DAYS	NUMBER OF CLOUDY DAYS
January	7	8	16
February	5	8	5
March	5	9	17
April	6	9	15
May	6	11	14
June	7	10	13
July	12	12	7
August	12	11	8
September	10	9	11
October	10	8	13
November	6	7	17
December	7	6	18
Annual	93	108	164

*A clear day is defined as one with 0-30% cloud cover, partly cloudy is one with 40-70% and cloudy from 80-100% cloud cover.

EXTENDED OCCURRENCES OF DRY AND WET PERIODS

Extended periods of drought conditions have existed in the study area in its more recent climatic past. Considering a combination of factors including precipitation, temperatures, soil-water properties and depth of rooting zones, the fluctuations in soil moisture balance in the last 60 years in Mandan (Morton County) is depicted in Figure 13. The graph shows a prolonged dry spell in 1915 through 1925 and the protracted drought of the "dust bowl" years from 1934 through about 1940.

Milder prolonged soil moisture deficits are evident between 1955 and 1965 and the most recent dry conditions in 1974, 1975 and 1976 are also evident in the graph. Wet periods characterize the interval of years between sequences of drought periods.

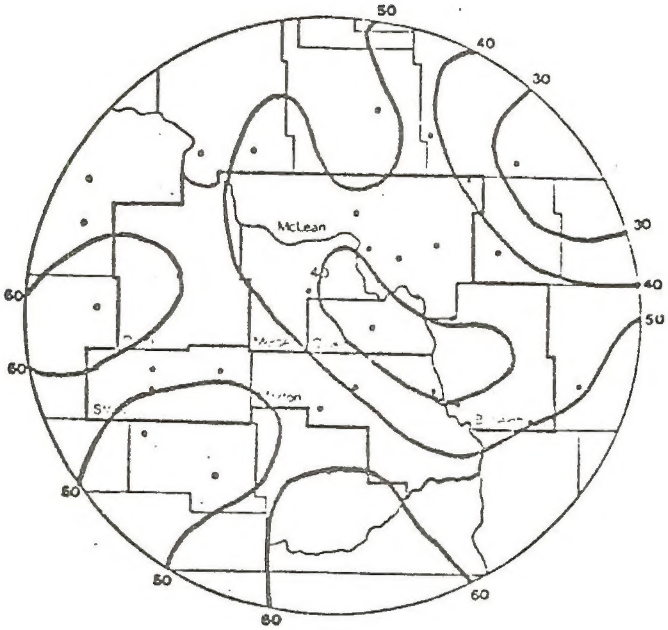


Figure 12. Mean Annual Number of Hail-Days in a 20-Year Period Across the Study Area

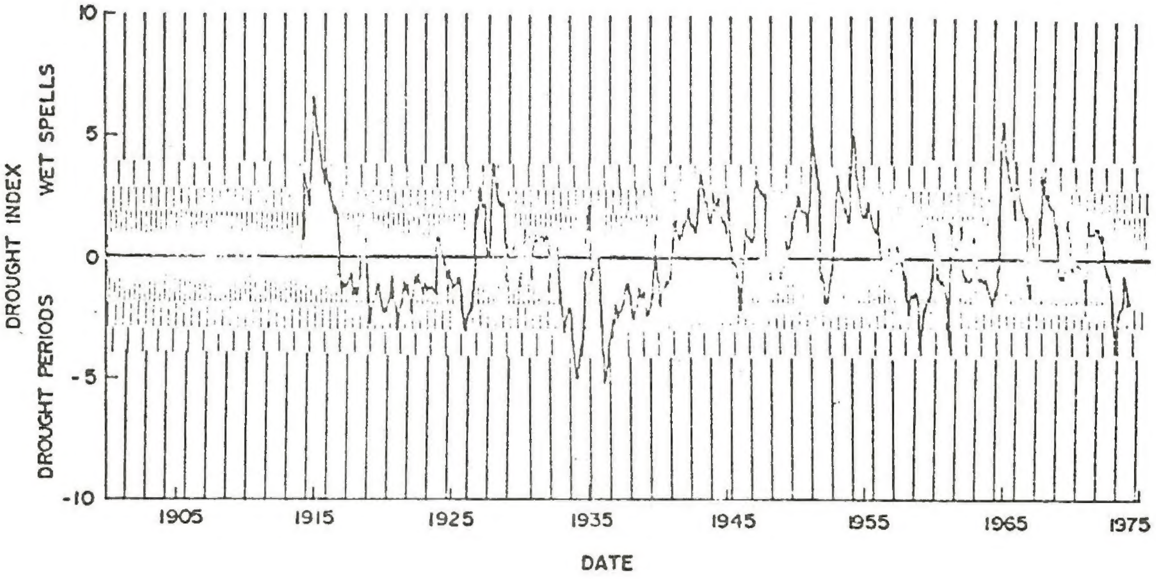


Figure 13. Relative Indices of Drought and Wet Spell Periods in Mandan, North Dakota From 1905 through 1975

CHAPTER II
WIND AND ATMOSPHERIC STABILITY: A DESCRIPTION OF THE EXISTING ENVIRONMENT

The spatial distribution of pollutants emitted and dispersed into the air is a function of the physical characteristics of the pollutant source and the atmospheric environment into which the pollutants are introduced. The critical properties of the source are its location, height above ground and, if the effluent is gaseous, the buoyancy and momentum of the pollutant stream. Given these initial source conditions, the dispersal of the pollutants once released is determined by the spatial and temporal properties of the boundary-layer atmosphere, namely, the stability and wind structure of the lowest few kilometers above the ground. Atmospheric stability describes the tendency for vertical motion in the atmosphere and determines the depth to which pollutant dispersal may occur. The vertical distribution of the wind velocity through this depth then determines the spatial distribution of the pollutants.

SOURCES OF DATA

In predicting pollutant ground-level concentrations from a given source(s), atmospheric diffusion models require a number of input parameters which include the mean wind speed, wind direction and a classification of the atmospheric stability in the air layers where mixing is expected to occur. An air pollution climatology of a region should include a description of these data types for both short and long-term periods. However, direct measurements of the wind profile and atmospheric stability in the seven-county area of western North Dakota are few and are available only for short periods of time. Surface weather data are collected by the National Weather Service (NWS) at four sites in and near the study area, namely in Bismarck, Dickinson, Minot and Williston. The records from these stations are the only long-term meteorological data available, and are used as the basic input data for describing the air pollution climatology of the study area. Other data sources include a one-year period of wind and temperature profile observations taken from instrumentation of a 100-meter tower maintained by North Dakota State University (NDSU) near Dunn Center, and from rawinsonde soundings at the NWS station in Bismarck. Surface and boundary layer data collected in some recent field programs, i.e., the North Dakota Regional Environmental Assessment Program (N.D. REAP) and the Northern Great Plains Resources Program (NGPRP) are not available in time for this report.

The surface weather data from the NWS stations in Bismarck, Dickinson, Minot and Williston consist of hourly observations of sea level pressure, temperature, dew point temperature, wind direction and speed, total sky cover and cloud ceiling height. These observations were obtained on magnetic tape from the National Climatic Center (NCC) and they cover varying periods of record: Bismarck 1948-1974, Williston 1950-1974, Dickinson 1948-1964, and Minot 1948-1974. Only eight observations per day, instead of 24, were recorded by the NCC on tape after 1964.

One full year of data from September 1975 through August 1976 are available from the NDSU meteorological tower site near Dunn Center. The tower instrumentation, constructed and maintained by North Dakota State University (NDSU) through funds granted by Natural Gas Pipeline Company (NGPL) collects wind speed, wind direction and temperature data at each of 10m, 50m and 100m levels above the ground.

Several studies (Hosler, 1961, Holzworth, 1972, 1974a, b) have analyzed rawinsonde sounding data (including data from Bismarck) for deriving parameters which describes air pollution climatology of selected regions. A rawinsonde is a free-ascent balloon carrying an instrument package with sensors for measuring pressure, temperature and humidity and which are tracked by a theodolite to determine wind speed and wind direction. Holzworth based his analyses on the rawinsonde soundings made on 1200 and 0000Z from 1960-1964.

Limited amount of temperature and wind profile data are also available from tower instrumentation near Hannover and Dickinson, North Dakota (Crawford, 1976). These data types are being collected by NDSU with funds granted the Surface, Environment and Mining (SEAM) program of the U.S. Forest Service.

The locations of the sources described above and the seven-county study area are displayed in Figure 14.

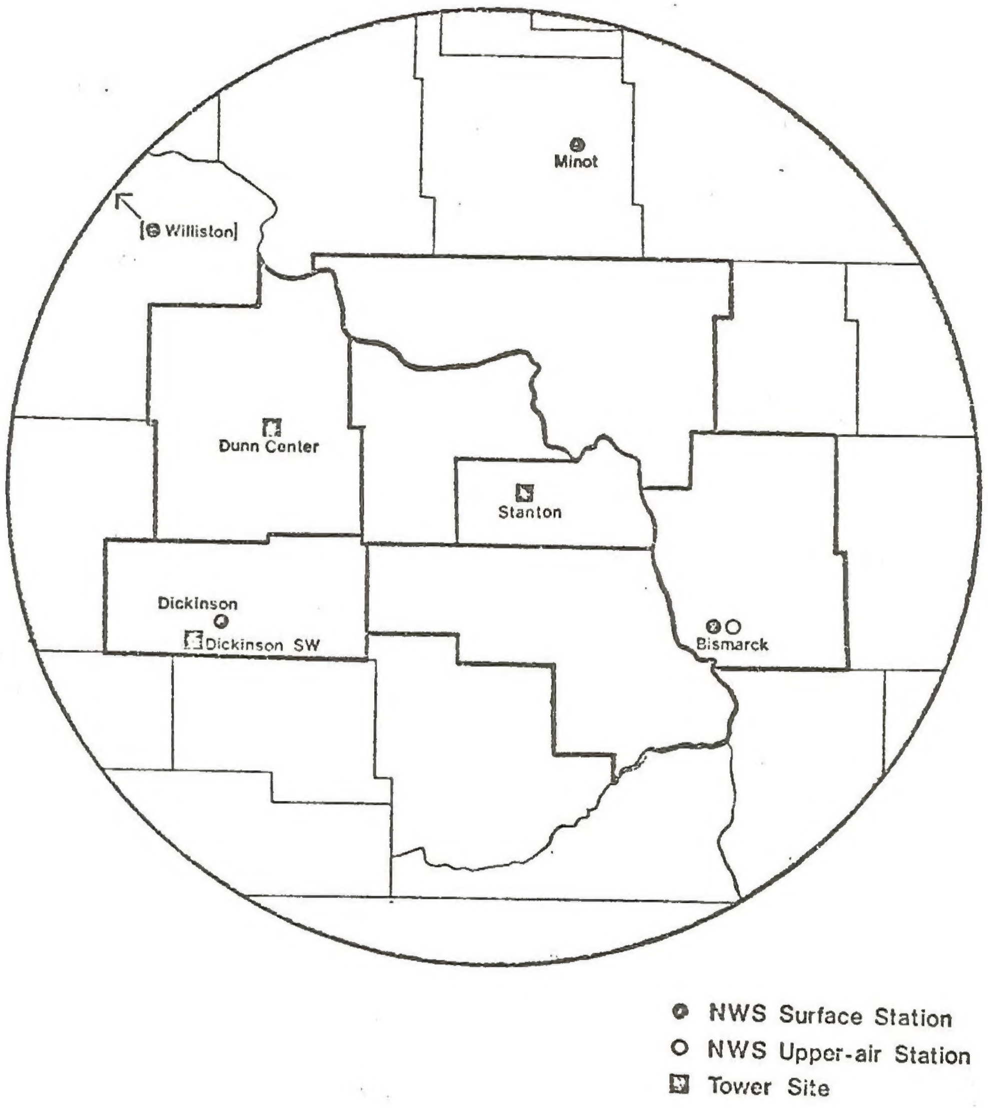


Figure 14. The Station Locations of Data Sources Used in Wind and Stability Analyses

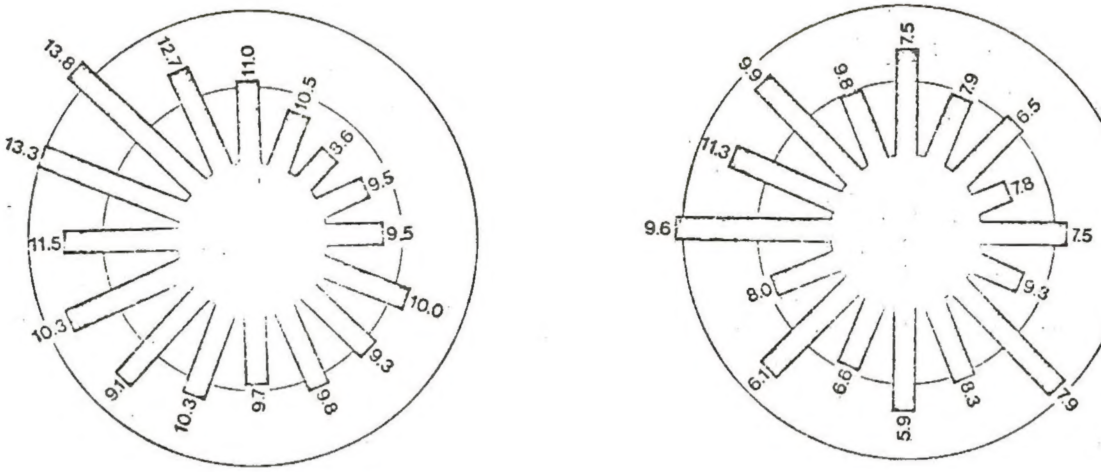
WIND CLIMATOLOGY

Surface Wind

Joint wind speed/wind direction percent frequency distributions (wind roses) were calculated from the hourly observation data available from the four NWS stations in or near the study area. The annual wind roses are depicted in Figure 15 for Bismarck, Dickinson, Minot, and Williston. The wind rose data for each month and the annual average are tabulated in Tables 10 through 13 for each of the four NWS stations using all available records in period 1948-1974.

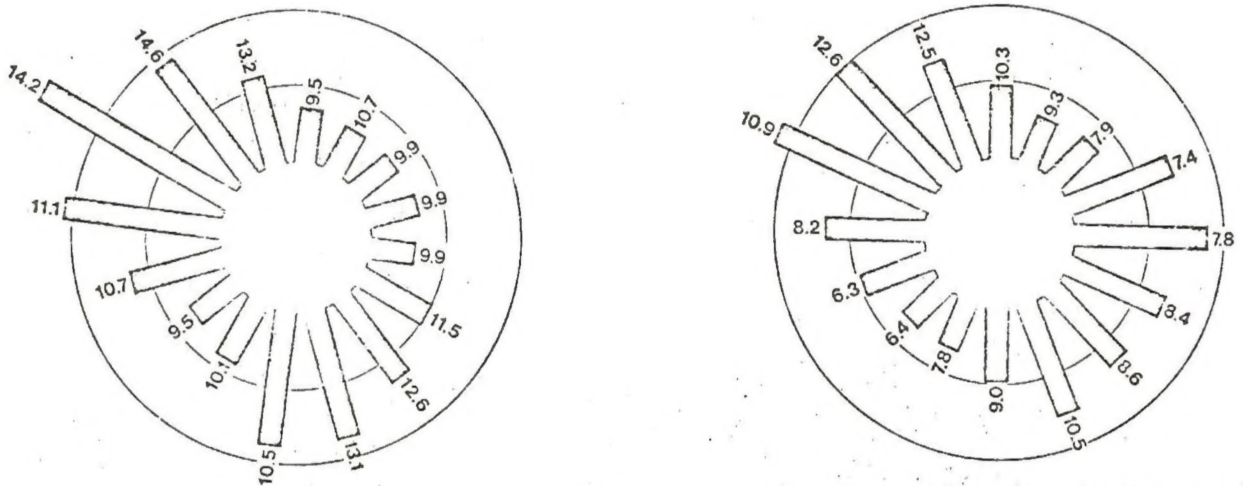
The wind data prior to 1964 obtained from NCC are from hourly observations. After 1964 however, the data on tape included only three-hourly data. The effects on the wind rose data of analyzing only eight observations per day instead of 24 were determined. The procedure involved the calculation of wind roses using the full period of record (1948-1974) and comparing the result to those obtained using only the 1948-1964 data analyses showed that the differences between the wind roses, despite 10 additional years of data, was minimal and considered insignificant. The 1948 to 1964 wind rose data will be presented in a computer printout form as an attachment to this report.

The prominent features of the general surface wind climatology of the study area are noted from the data presented in Tables 10 through 13. The most frequent and the highest wind speeds occur out of the northwest quadrant, especially in the colder months. During the warmer months, the frequencies of wind direction are more uniform than



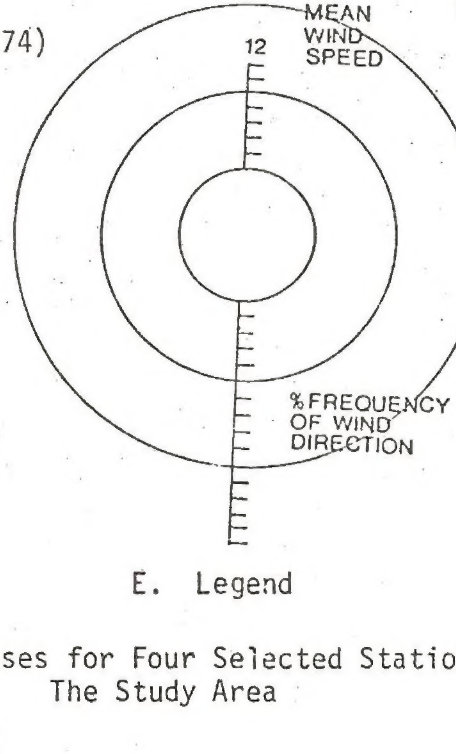
A. Dickinson (1948-1964)

B. Bismarck (1948-1974)



C. Minot (1948-1974)

D. Williston (1950-1974)



E. Legend

Figure 15. Wind Roses for Four Selected Stations In and Near The Study Area

TABLE 10 MONTHLY MEAN WIND SPEEDS AND PERCENT FREQUENCY OF WIND DIRECTION FROM NWS BISMARCK HOURLY OBSERVATION DATA, 1948-1974[1]

Wind Direction	MONTH																									
	January		February		March		April		May		June		July		August		September		October		November		December		Annual	
	%WD[2]	MWS[3]	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS
N	4.3	10.8	4.2	10.3	4.9	11.2	6.3	12.0	6.1	11.3	4.7	9.9	4.6	8.6	4.5	9.1	4.2	9.4	4.0	9.7	4.2	10.2	3.5	9.0	4.6	10.3
NNE	2.7	8.3	2.4	7.9	3.5	9.9	4.4	10.6	4.5	10.8	3.8	9.9	3.9	7.7	3.4	8.5	2.6	9.1	2.9	9.0	2.5	9.1	2.0	8.2	3.2	[illegible]
NE	2.9	6.1	3.4	6.3	3.2	8.6	4.4	10.7	4.9	9.5	4.1	8.9	4.2	6.9	3.7	6.5	3.1	7.5	3.1	7.9	2.3	7.5	3.0	6.2	3.5	[illegible]
ENE	6.7	6.5	7.6	6.4	6.2	7.0	7.1	9.7	8.3	9.2	3.1	8.8	7.9	7.1	8.9	6.9	7.4	7.1	6.4	6.7	5.2	6.5	7.2	6.2	7.3	7.4
E	9.1	6.9	10.8	7.6	8.5	7.8	8.1	9.8	9.4	10.0	8.2	8.9	9.3	7.6	10.7	7.7	9.0	7.5	6.9	6.3	7.0	6.8	9.0	6.5	8.8	7.8
ESE	6.1	6.1	7.3	7.7	7.7	9.0	7.2	10.6	8.2	10.4	7.2	9.8	8.3	8.5	9.2	8.6	6.4	8.4	5.5	6.5	5.5	6.4	6.2	6.3	7.1	8.4
SE	5.8	7.0	6.4	8.1	7.3	8.9	5.8	10.5	7.0	10.5	6.6	10.1	7.6	8.9	7.8	9.0	6.1	9.1	5.9	7.3	5.3	6.8	6.1	7.0	6.5	8.6
SSE	5.2	8.0	5.9	9.1	7.6	10.4	7.5	11.6	8.9	12.2	9.0	11.0	9.7	10.4	10.0	11.1	3.3	11.1	7.8	11.1	5.6	8.4	5.8	8.3	7.6	10.5
S	2.9	6.0	3.5	7.4	4.1	8.4	4.8	11.2	5.2	10.5	6.2	9.6	5.7	8.8	6.1	10.2	5.9	9.4	5.1	9.5	4.3	7.5	3.8	6.8	4.8	9.0
SSW	2.3	6.4	3.0	6.7	3.1	8.2	3.5	9.1	3.4	9.4	3.9	7.9	3.6	7.8	3.1	8.1	3.5	8.0	3.8	7.9	3.7	7.0	2.8	6.1	3.3	7.8
SW	3.6	5.5	3.5	6.2	3.0	6.7	2.7	7.1	2.8	8.4	3.8	7.2	2.9	6.2	2.7	6.2	3.7	5.9	4.1	6.7	4.4	6.1	3.9	5.5	3.4	6.4
WSW	6.1	6.0	5.0	5.5	3.8	5.9	3.6	7.3	3.8	8.0	5.2	8.1	4.0	6.1	3.6	5.6	5.0	6.4	5.6	6.3	5.9	5.6	6.3	5.8	4.8	6.3
W	8.4	8.0	6.5	7.9	5.3	8.3	5.0	10.4	4.7	9.3	6.9	8.7	5.3	7.5	5.2	6.8	7.7	8.6	7.4	8.1	8.4	8.3	8.6	7.6	6.7	8.2
WNW	13.1	10.9	12.5	10.5	11.2	10.9	9.6	12.2	8.4	11.9	10.0	10.7	8.9	9.4	7.8	8.5	11.2	11.1	12.7	10.7	14.7	12.1	14.1	11.5	11.2	10.9
NW	12.4	13.1	10.6	12.8	12.0	13.2	10.0	13.2	7.5	13.4	7.2	11.1	7.5	10.3	7.4	10.1	9.2	11.7	11.5	12.6	13.2	13.8	11.9	13.4	10.0	12.6
NNW	8.3	13.7	7.4	12.9	8.4	13.3	9.9	14.0	6.3	13.0	5.3	10.7	6.0	10.4	6.0	10.5	6.6	11.0	7.4	12.1	7.8	13.2	5.8	12.4	7.1	12.5
Total[5]	99.9[4]	8.9	100.0	8.8	99.8	9.8	99.9	11.1	100.0	10.8	100.2	9.6	99.9	8.5	100.1	8.6	99.9	9.1	93.8	9.1	100.0	9.3	100.0	8.6	99.9	9.4

[1] All Data Available in WS/WD by SC computer output

[2] Percent Frequency of Wind Direction

[3] Mean Wind Speed in Knots

[4] Differences in figures and 100% attributable to round-off errors

[5] Percent frequency of calms is distributed proportionately

TABLE 11 MONTHLY MEAN WIND SPEEDS AND PERCENT FREQUENCY OF WIND DIRECTION FROM NWS DICKINSON HOURLY OBSERVATION DATA, 1948-1964[1]

Wind Direction	MONTH																									
	January		February		March		April		May		June		July		August		September		October		November		December		Annual	
	%WD[2]	MWS[3]	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS
N	2.0	9.4	2.4	9.8	3.8	10.6	4.8	10.6	4.6	10.8	4.8	9.2	5.0	8.7	5.0	9.0	3.9	8.7	2.9	8.9	2.0	10.0	1.5	7.8	3.6	9.5
NNE	1.7	9.5	1.8	9.9	3.1	11.7	4.2	12.1	4.2	11.7	4.6	11.4	4.1	9.2	3.9	10.0	3.0	9.9	2.7	10.8	1.6	11.6	1.5	9.2	3.0	10.7
NE	2.1	9.1	1.9	10.0	2.5	10.0	4.4	12.1	5.4	10.8	4.7	10.2	3.9	8.8	4.0	8.4	2.6	9.6	2.6	10.2	1.6	9.0	2.1	8.1	3.2	9.9
ENE	2.7	9.1	2.0	10.0	2.7	9.2	4.5	11.8	5.0	11.1	4.5	10.8	5.1	9.0	5.1	9.4	3.1	9.9	2.5	9.2	1.3	8.1	2.0	8.2	3.4	9.9
E	2.4	9.2	2.6	10.5	2.8	10.3	3.6	11.6	4.9	10.8	4.3	9.8	5.3	9.5	5.0	9.1	3.2	10.1	1.8	8.4	1.8	10.5	2.1	9.1	3.3	9.9
ESE	3.0	10.3	3.1	11.4	5.6	13.0	5.4	13.6	7.7	12.0	6.9	11.9	7.5	10.4	8.2	10.4	5.1	11.7	3.2	10.6	2.4	9.5	3.5	10.5	5.1	11.5
SE	3.7	10.9	5.1	12.3	7.2	13.5	6.4	14.5	8.6	13.7	8.8	13.2	9.1	11.3	9.1	11.7	6.5	12.4	5.5	12.3	3.6	11.6	4.4	11.2	6.5	12.6
SSE	5.9	12.4	7.0	12.6	9.7	14.3	8.8	14.3	10.3	14.1	9.0	12.5	10.8	12.3	11.2	13.0	9.5	12.6	9.3	13.1	5.8	13.3	6.0	12.3	8.6	13.1
S	7.2	10.6	8.9	11.7	8.3	11.2	8.7	11.7	7.6	10.6	8.5	9.6	9.7	9.5	9.7	10.5	10.0	9.9	9.9	10.3	8.9	11.1	8.5	9.7	8.8	10.5
SSW	3.8	10.7	4.9	10.7	3.5	10.0	4.1	10.3	3.3	10.6	3.4	9.3	4.3	9.8	3.9	9.1	3.9	9.0	5.1	10.3	5.5	10.6	4.7	9.9	4.2	10.1
SW	4.2	10.4	4.2	10.7	3.0	9.5	2.7	9.7	2.4	10.8	3.0	8.8	2.4	7.6	2.5	8.3	3.0	8.0	4.4	9.4	5.1	9.9	5.0	9.9	3.5	9.5
WSW	10.2	11.6	8.2	11.5	4.9	10.2	4.3	10.7	3.8	11.5	5.1	11.0	3.5	9.0	3.7	8.9	5.5	9.5	8.0	10.2	9.0	10.8	9.7	11.2	6.3	10.7
W	16.1	12.1	13.9	11.7	8.2	11.2	7.3	11.4	6.3	10.7	8.6	11.1	6.3	9.0	6.2	9.2	10.0	10.7	12.7	10.5	16.0	11.3	16.7	11.7	10.7	11.1
WNW	18.4	14.9	17.1	14.7	15.2	14.3	12.7	14.6	10.1	14.5	11.7	14.2	10.0	12.1	9.3	11.2	14.2	13.4	14.9	13.9	19.9	15.4	19.7	15.1	14.4	14.2
NW	10.7	15.5	10.4	15.0	12.4	15.9	9.1	15.4	9.1	14.3	7.1	12.8	6.9	11.8	7.3	11.6	10.0	14.0	9.3	14.5	10.8	16.4	9.2	15.4	9.3	14.6
NNW	5.9	15.2	5.5	12.3	7.0	13.5	9.1	14.0	6.7	13.7	4.9	11.7	6.1	11.0	5.8	11.6	6.3	12.3	5.1	13.1	4.9	15.1	3.5	12.4	5.9	13.2
Total[5]	99.9[4]	12.5	99.8	12.4	99.8	12.7	100.1	13.0	100.0	12.5	99.9	11.5	100.0	10.4	99.8	10.5	99.8	11.4	99.9	11.6	100.2	12.7	100.1	12.0	99.8	11.9

[1] All data also available in WS/WD by SC computer output

[2] Percent Frequency of Wind Direction

[3] Mean Wind Speed in Knots

[4] Difference between figures and 100% is attributable to round off errors

[5] Percent frequency of calms is distributed proportionately

TABLE 12 MONTHLY MEAN WIND SPEEDS AND PERCENT FREQUENCY OF WIND DIRECTION FROM NWS MINOT HOURLY OBSERVATION DATA, 1948-1974[1]

Wind Direction	MONTH																									
	January		February		March		April		May		June		July		August		September		October		November		December		Annual	
	%WD[2]	MWS[3]	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS
N	5.4	10.7	4.6	11.5	6.1	11.9	7.8	12.6	6.9	12.0	6.1	10.9	5.4	9.3	5.6	10.5	4.9	10.5	4.5	10.2	4.1	10.6	3.7	9.9	5.4	11.0
NNE	3.1	10.3	2.3	10.1	3.8	11.7	5.6	11.2	5.9	11.7	5.0	10.6	4.1	8.9	3.6	10.1	3.3	9.9	3.5	10.7	2.8	9.6	2.7	8.8	3.8	10.5
NE	2.0	6.6	1.6	8.3	2.0	7.5	3.6	10.9	3.7	9.9	3.6	9.0	3.5	7.9	3.5	8.1	2.9	8.7	1.7	8.3	1.4	7.7	1.8	7.7	2.7	8.6
ENE	2.2	8.3	3.1	9.4	2.9	9.7	4.4	11.6	5.5	10.5	4.4	9.7	3.4	8.6	4.8	8.9	3.1	9.2	1.8	8.9	2.0	8.4	2.8	8.8	3.4	9.5
E	3.0	9.5	3.6	9.4	4.1	10.4	4.3	10.8	5.4	10.2	5.1	9.4	3.9	8.9	4.5	9.0	3.3	9.3	2.3	8.0	2.1	8.0	3.3	8.6	3.7	9.5
ESE	4.4	9.4	5.7	9.8	7.6	10.5	6.6	11.6	0.7	11.1	7.3	10.8	6.5	9.6	7.5	9.5	5.7	9.8	4.7	8.4	4.1	9.2	4.9	9.0	6.1	10.0
SE	4.0	7.6	5.4	8.8	6.4	10.0	4.7	10.5	6.8	10.8	6.5	10.4	6.9	8.9	7.8	9.0	5.8	9.4	5.1	8.8	4.2	8.0	4.6	8.4	5.7	9.3
SSE	3.5	8.4	4.6	9.0	6.4	10.0	6.3	10.8	6.7	11.0	6.6	10.0	7.4	9.4	7.9	9.5	5.9	9.8	5.6	9.6	4.4	9.7	3.9	8.5	5.8	9.8
S	3.9	9.0	4.4	9.6	4.2	9.6	4.8	10.9	4.8	11.1	5.0	9.8	5.6	9.3	5.8	9.4	5.2	9.6	5.7	9.8	4.1	9.3	3.8	8.4	4.8	9.7
SSW	5.3	10.3	6.2	10.6	5.6	10.4	6.0	11.4	5.8	10.8	5.6	9.9	6.7	9.2	6.3	9.9	6.5	10.0	7.5	10.5	6.7	10.1	6.2	10.7	6.2	10.3
SW	7.4	9.9	8.4	9.6	6.0	9.6	5.5	9.2	6.5	9.0	7.8	9.0	7.7	8.0	7.0	8.0	8.3	8.6	9.6	9.2	9.4	9.9	9.1	9.4	7.7	9.1
WSW	10.7	11.3	9.6	10.4	6.2	10.3	6.5	11.3	6.0	10.4	8.3	10.3	7.7	8.7	7.0	9.2	8.6	10.0	10.2	10.3	9.7	10.3	11.3	10.9	8.5	10.3
W	11.0	12.6	9.0	11.4	6.8	11.8	6.0	12.2	4.7	11.2	7.0	11.5	6.3	10.2	6.1	9.7	8.6	11.6	8.5	11.7	9.5	11.4	9.7	11.5	7.7	11.5
WNW	13.4	14.3	11.6	13.4	8.9	13.1	8.3	14.3	6.8	13.8	8.2	12.5	8.1	11.4	6.9	11.4	10.2	13.5	11.4	12.9	13.9	13.8	13.1	14.0	10.1	13.3
NW	13.2	14.2	12.6	14.3	13.9	14.5	11.1	14.5	8.6	14.1	7.7	12.3	9.5	11.7	8.9	11.5	11.3	13.0	11.6	13.7	13.6	15.4	12.8	14.7	11.2	13.8
NNW	7.5	13.6	7.4	12.8	8.9	13.3	9.3	14.2	7.1	12.9	5.8	11.3	7.0	10.6	6.7	11.8	6.2	11.6	6.3	12.9	7.5	13.8	6.4	12.9	7.2	12.7
Total[5]	100.0	11.3	100.1[4]	11.2	99.8	11.5	99.8	12.1	99.9	11.4	100.0	10.6	99.7	9.6	99.9	9.8	100.0	10.7	100.0	10.8	100.0	11.5	100.1	11.1	100.0	11.0

[1] All data also available in WS/WD by SC computer output

[2] Percent Frequency of WD

[3] Mean Wind Speed in Knots

[4] Difference between figures and 100% is attributable to round off errors

[5] Percent frequency of calms is distributed proportionately

TABLE 13 MONTHLY WIND SPEEDS AND PERCENT FREQUENCIES OF WIND DIRECTION FROM NWS WILLISTON HOURLY OBSERVATION DATA, 1950-1974[1]

Wind Direction	MONTH																									
	January		February		March		April		May		June		July		August		September		October		November		December		Annual	
	%WD[2]	MWS[3]	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS	%WD	MWS
N	7.1	7.2	6.6	7.7	7.9	8.7	3.4	8.6	7.7	8.3	6.8	6.8	8.0	6.3	8.7	6.6	7.0	8.0	6.8	7.4	5.7	7.3	5.4	6.7	7.2	7.5
NNE	4.5	7.5	4.3	7.4	4.8	8.0	5.4	9.3	5.2	8.9	5.2	8.5	5.7	7.4	6.3	7.6	4.0	7.7	4.2	8.0	3.3	7.9	3.5	6.7	4.7	7.9
NE	5.1	5.6	4.9	6.0	5.6	6.4	7.0	7.9	6.4	7.5	6.5	6.6	5.6	6.2	6.5	6.1	5.6	5.7	4.3	6.6	3.3	6.9	3.7	5.7	5.4	6.5
ENE	2.0	5.9	2.1	6.5	2.1	6.7	3.8	10.0	3.4	9.1	2.8	8.7	2.9	7.0	2.5	7.5	2.1	7.4	1.6	7.3	1.5	7.0	1.6	6.5	2.4	7.8
E	5.3	6.5	6.3	7.2	6.1	7.8	7.2	9.2	7.9	8.6	7.1	8.6	5.7	7.3	6.7	6.9	5.1	6.6	4.0	6.0	3.6	6.5	5.0	6.6	5.8	7.5
ESE	2.6	8.1	3.7	8.4	4.0	9.9	4.3	10.7	5.6	10.8	4.5	10.3	4.4	8.9	4.6	8.7	3.1	9.3	2.2	8.1	2.5	8.3	2.8	7.9	3.7	9.3
SE	6.5	6.1	7.9	7.5	10.9	8.3	10.1	9.1	11.8	9.5	9.9	8.5	10.7	8.1	12.0	7.6	10.0	8.0	8.4	7.2	7.2	6.8	8.0	6.1	9.5	7.9
SSE	3.6	6.3	4.4	7.3	5.8	8.7	5.1	9.9	6.1	9.4	6.0	8.6	7.4	8.4	7.0	8.8	5.6	8.6	5.1	8.0	4.5	7.3	4.6	6.6	5.5	8.3
S	6.8	4.8	7.5	5.5	5.8	6.0	5.5	6.6	6.1	7.1	6.0	6.8	7.8	5.8	7.5	6.1	7.2	6.2	7.5	5.9	8.0	5.5	3.2	5.1	7.0	5.9
SSW	5.6	5.9	5.5	5.9	3.6	6.7	3.3	8.2	3.4	7.7	4.0	6.8	4.0	6.5	4.0	6.5	4.7	7.0	5.5	6.6	6.0	6.5	6.3	5.8	4.6	6.6
SW	11.1	5.6	10.1	5.8	6.1	6.4	5.5	7.1	5.2	6.8	6.5	6.3	5.5	5.9	6.1	5.9	8.0	5.9	10.0	6.0	11.3	6.2	11.5	5.6	9.0	6.1
WSW	6.3	8.2	5.6	7.7	3.7	8.1	3.1	8.9	3.0	9.3	4.5	9.3	3.1	7.5	3.2	7.9	4.4	7.7	5.3	7.4	5.9	7.7	6.7	7.4	4.5	8.0
W	12.1	9.7	12.0	9.0	10.1	9.7	8.4	11.2	8.7	10.9	12.0	10.6	8.9	8.9	7.3	9.1	10.9	9.7	12.3	9.4	11.8	8.6	11.7	8.5	10.[illegible]	9.6
WSW	7.8	11.1	6.5	10.6	7.3	11.4	7.5	12.9	6.7	12.6	6.9	10.5	6.6	10.4	6.0	11.1	8.4	11.9	8.3	11.3	10.1	11.1	8.0	10.9	7.5	11.3
NW	8.1	9.2	8.1	9.7	10.1	10.4	9.4	10.7	8.2	11.3	7.4	9.3	8.3	8.5	6.9	9.0	9.2	10.0	10.0	9.8	10.9	10.3	8.8	9.9	8.8	9.9
NNW	5.6	10.2	4.5	10.4	6.0	10.1	6.1	10.9	4.5	10.3	3.9	9.0	5.5	8.4	4.5	9.1	4.8	9.3	4.6	10.4	4.5	9.6	4.3	10.1	4.9	9.8
Total[5]	100.1[4]	7.6	100.0	7.7	99.9	8.6	100.1	9.6	99.9	9.4	100.0	8.6	100.1	7.7	99.8	7.7	100.1	8.3	100.1	8.0	100.1	7.9	100.1	7.3	100.0	8.2

[1] All data also available from WS/WD by SC computer output

[2] Percent Frequency of Wind Direction

[3] Mean Wind Speeds in Knots

[4] Differences in figures and 100% is attributable to round-off errors

[5] Percent frequency of calms is distributed proportionately

during winter with the most frequent and fastest winds bearing from the southeast quadrant. The highest monthly wind speeds occur in early spring and in winter. Mean annual wind speeds vary among the four stations from 8.2 knots at Minot to 11.9 knots at Dickinson.

The degree of differences in surface wind climatology among the four stations may be deduced from Table 14. The lower annual mean wind speed at Williston, 8.2 knots, as opposed to the 11.9 knots annual mean wind speed at Dickinson, is the most notable of the minor differences evident from Table 14. Williston shows lesser wind speeds and the lesser frequency of northwesterly winds when compared to the other stations to the east.

TABLE 14 COMPARISON OF SURFACE WIND CLIMATOLOGICAL FEATURES BETWEEN FOUR NWS SURFACE WIND STATIONS IN OR NEAR THE STUDY AREA

Feature	(1948-1974) Bismarck	(1948-1964) Dickinson	(1948-1974) Minot	(1950-1974) Williston
Annual Mean Wind Speed[1] (MWS)	9.4	11.9	11.0	8.2
Highest Monthly MWS	11.1-April	13.0-April	12.1-April	9.6-April
Lowest Monthly MWS	8.5-July	10.4-July	9.6-July	7.3-Dec.
Prevailing Annual Wind Direction [2]	11.2%-WNW	14.4%-WNW	11.2%-NW	10.5%-W
Least Prevalent Annual Wind Direction	3.2%-NNE	3.0%-NNE	2.7%-NE	2.4%-ENE
Prevailing Wind Direction in January	13.1%-WNW	18.4%-WNW	13.4%-WNW	12.0%-W
Least Prevalent Wind Direction in Jan.	2.3%-SSW	1.7%-NNE	2.0%-NE	2.0%-ENE
Prevailing Wind Direction in July	9.7%-SSE	10.7%-SE	9.5%-NW	10.7%-SE
Least Prevalent Wind Direction in July	2.9%-SW	2.9%-ENE	3.9%-ENE	2.9%-ENE

[1] Wind Speed in Knots

[2] Percent of time in month when given wind direction was observed

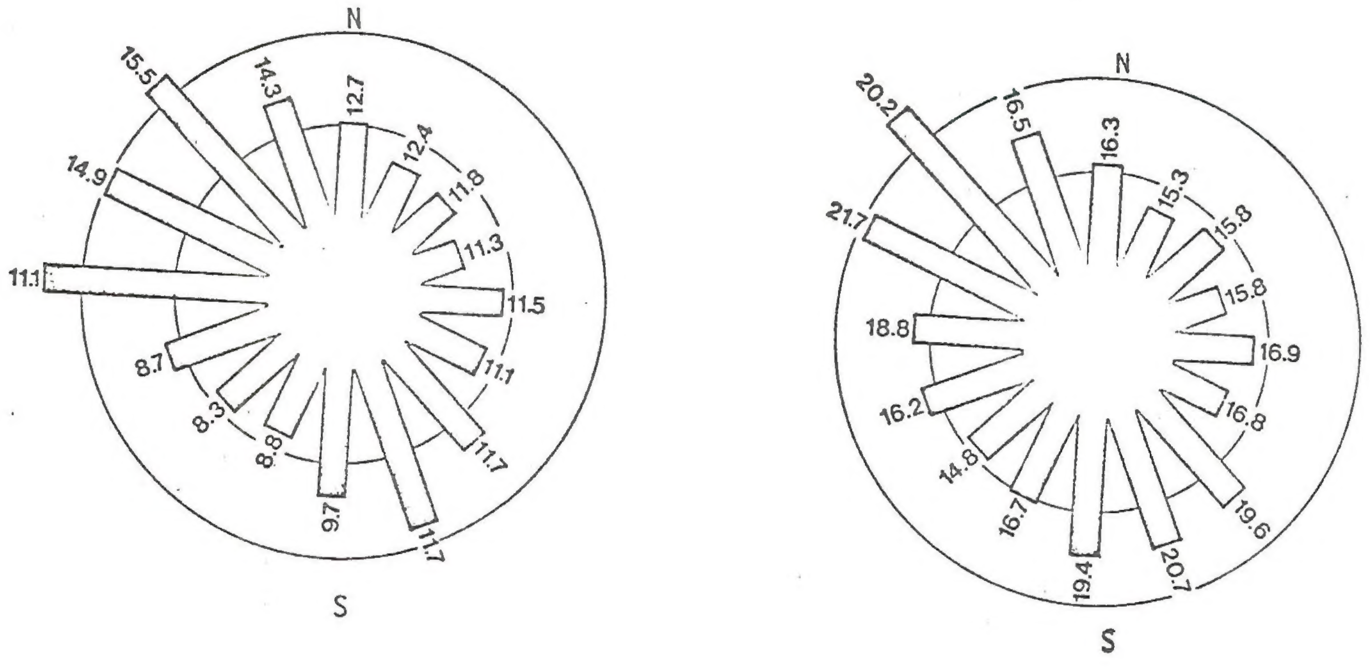
The wind speed differences among the locations may be due to the differences in exposure heights of the wind speed sensors at the four NWS sites in addition to the differences due to the shorter period of record for Dickinson. Wind speeds near the surface generally increase exponentially with height.

There is a generally good agreement of the surface wind data among the four stations. The surface winds in the seven county study area are relatively higher in the colder months than other parts of the year. Higher wind speeds tend to decrease the mass of pollutant emitted into a given volume of air passing over an effluent source. Northwesterly winds prevail in the study area. However, winds from all compass points occur at relatively equal frequencies across the region.

Winds Aloft

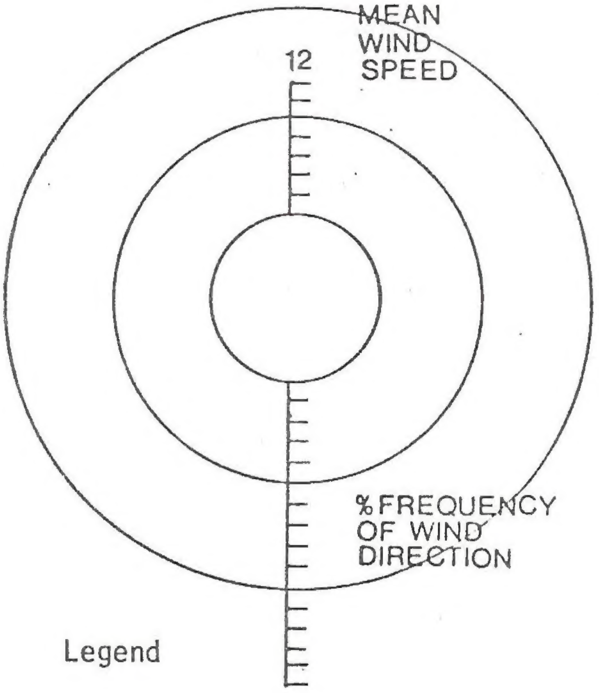
Wind roses for 10m and 100m heights were computed from one year of data collected at a tower site near Dunn Center from September, 1975 through August, 1976. The results are shown in Figure 16. The monthly wind speed/wind direction frequency distribution for the 10m height is given in Table 15. The one-year distribution of the 100m wind is also included in Table 15.

Wind at 10 meter Height. The one-year average of 10m wind speed at Dunn Center was 11.9 miles per hour. The highest mean monthly wind speed occurred in January, 13.7 mph which was followed closely by a 13.4 mph mean in April. The highest monthly wind speeds were found in April for all four NWS stations in or near the seven county area.



10 M

100 M



Legend

Figure 16. Wind Roses From Dunn Center at 10m and 100m, September, 1975 through August, 1976

TABLE 15 MONTHLY WIND SPEEDS AND PERCENT FREQUENCIES OF WIND DIRECTION AT DUNN CENTER FROM AUGUST, 1975 THROUGH JULY, 1976

	10m MONTH																								100m	
WIND DIRECTION	January %WD[1]	January MWS[2]	February %WD	February MWS	March %WD	March MWS	April %WD	April MWS	May %WD	May MWS	June %WD	June MWS	July %WD	July MWS	August %WD	August MWS	September %WD	September MWS	October %WD	October MWS	November %WD	November MWS	December %WD	December MWS	One-Year Average %WD	One-Year Average MWS	One-Year[3] Average %WD	One-Year[3] Average MWS
E	3.4	14.4	5.0	11.7	6.5	13.0	3.2	15.8	9.0	14.4	7.2	13.2	1.7	9.7	4.0	9.8	5.5	12.2	4.6	10.0	5.6	14.2	3.6	11.3	5.0	12.7	5.4	16.3
NNE	0.8	16.2	1.7	12.5	3.3	15.8	7.8	18.1	4.0	12.9	3.0	13.1	3.5	8.7	5.2	8.2	2.5	10.9	6.0	11.3	3.6	10.0	2.6	10.8	3.6	12.4	3.5	15.3
NE	0.1	8.0	1.9	6.8	3.9	13.6	4.8	15.0	4.4	11.8	4.0	12.5	2.7	9.5	4.1	7.9	2.0	9.4	5.2	14.3	4.1	10.1	3.5	13.0	3.3	11.8	4.2	15.8
ENE	0.1	7.0	1.6	9.0	2.8	15.9	7.0	11.9	2.5	7.7	2.6	10.7	2.0	9.9	5.1	9.0	1.2	8.5	2.8	14.5	3.5	13.0	1.6	10.6	2.7	11.3	3.0	15.8
E	0.3	5.8	3.9	10.1	4.3	14.8	10.0	12.2	4.0	10.1	5.3	10.3	5.6	12.0	9.9	9.3	3.3	11.3	1.3	8.2	3.0	15.1	5.8	12.3	4.6	11.5	4.3	16.9
ESE	0.4	8.7	2.5	11.6	2.0	8.4	5.6	11.9	4.6	10.6	2.6	12.8	10.8	12.5	10.1	10.5	2.7	10.8	3.3	10.3	4.2	10.0	2.6	12.2	4.1	11.1	3.3	16.8
SE	4.0	8.2	5.1	10.7	4.5	8.7	9.1	13.0	11.0	11.9	7.1	12.7	16.3	16.1	8.1	12.8	4.2	8.2	4.4	9.0	5.3	11.9	3.5	8.0	6.5	11.7	6.9	19.6
SSE	8.3	8.4	6.2	11.0	7.3	8.6	10.7	13.0	11.2	14.8	11.8	16.0	14.3	13.3	5.7	12.7	8.6	10.6	8.5	9.6	9.8	9.1	8.3	9.7	9.0	11.7	7.3	20.7
S	6.3	8.6	5.3	8.2	6.3	10.1	4.5	10.7	10.4	10.6	5.4	10.2	6.3	10.6	4.2	8.8	7.3	10.3	8.8	11.0	5.5	6.5	9.4	9.4	6.8	9.7	7.4	19.4
SSW	3.1	7.7	3.0	9.3	6.6	8.3	1.6	8.5	4.0	8.2	5.1	12.5	2.8	9.6	3.2	7.5	1.9	5.7	6.4	10.0	6.7	7.9	4.7	9.0	4.1	8.8	5.0	16.7
SW	5.3	9.2	8.3	9.5	3.0	8.9	2.7	8.8	4.3	7.1	4.8	9.3	3.2	9.3	4.2	7.9	2.1	5.1	4.1	8.7	6.4	7.8	5.8	7.5	4.6	8.3	4.5	14.8
WSW	6.3	10.5	8.3	10.3	8.0	9.0	2.2	6.6	5.2	8.3	6.5	10.0	2.3	7.0	5.1	5.3	2.7	4.6	7.2	8.6	7.4	9.4	6.9	9.2	5.9	8.7	5.8	16.2
W	17.7	13.2	13.4	12.8	11.8	10.6	5.8	8.2	8.8	9.1	12.6	13.5	7.8	8.1	10.8	12.9	10.4	8.6	10.8	10.6	16.0	8.9	16.3	10.5	12.1	11.1	10.2	18.8
WNW	17.4	17.0	10.0	14.6	12.8	17.6	10.0	14.0	4.1	11.2	8.1	14.7	6.7	14.1	9.6	16.2	11.0	13.2	11.5	15.5	8.6	10.6	7.9	13.2	9.9	14.9	9.5	21.7
NW	20.1	18.6	16.0	16.4	10.3	17.0	10.8	16.2	6.1	12.3	8.6	12.5	8.2	13.1	6.1	13.1	16.5	16.9	10.0	15.1	5.3	11.8	12.8	15.0	11.0	15.5	12.0	20.2
NNW	6.6	16.4	7.8	17.3	6.5	15.2	4.4	17.7	6.5	13.9	5.4	12.5	5.8	12.3	4.6	12.6	13.0	15.2	5.2	9.7	5.2	13.4	4.7	12.6	6.8	14.3	7.6	16.5
TOTAL	100.0	13.7	100.0	12.3	99.9	12.3	100.0	13.4	100.0	11.4	100.0	12.6	100.0	11.6	99.9	10.7	100.0	12.1	100.0	11.4	100.0	9.9	100.0	11.1	100.0	11.9	100.0	18.2

---

[1] Percent Frequency of Wind Direction

[2] Mean Wind Speed in Miles Per Hour

[3] 100m data from September, 1975 through August, 1976

The lowest monthly wind speed at Dunn Center for one year was recorded in November at 9.9 mph. Northwest winds prevailed during the year with westerly winds occurring 12.1% of the time. The wind roses at 10m for Dunn Center in Figure 16 compare closely with those for the four NWS stations shown in Figure 15.

The rapid increase of wind speed with height is evident from the 10m and 100m one-year wind speed data given in Table 15. The magnitude of this rate of increase is an important input in atmospheric dispersion modeling since the mean wind speed through the mixing layer is a critical factor in calculating the ground-level concentrations of pollutants at ground-level downwind from a given source. Since many major pollutant releases occur from elevated stacks, the surface wind frequently does not adequately represent the wind speed experienced by a plume and therefore, has limitations in atmospheric dispersion modeling. For the one-year period at Dunn Center, the mean 100m wind speed at Dunn Center was 18.2 mph, 6.3 mph higher than the 10m MWS. This increase occurred irregardless of wind direction which varied little with height through the tower depth.

ATMOSPHERIC STABILITY IN THE STUDY AREA

The most common and convenient index of atmospheric stability is the vertical temperature profile. A decrease in temperature with height of $1^{\circ}C/100m$, the adiabatic lapse rate, corresponds to neutral atmospheric stability, when air has neither a tendency to rise or descend. A rapid decrease in temperature with height, a superadiabatic lapse rate, indicates unstable conditions which enhance upward vertical motions and promotes favorable dispersal conditions. An increase in temperature with height, an inversion, causes subsidence and inhibits atmospheric diffusion.

Many atmospheric dispersion models, including the Environmental Protection Agency's (EPA) User's Network of Applied Modeling of Air Pollution (UNAMAP) programs, classify atmospheric stability into six categories as devised by Pasquill (1961). These six categories are given below:

A - Very unstable
B - Unstable
C - Slightly unstable
D - Neutral
E - Stable
F - Very stable

In the absence of continuous measurements of the vertical temperature profile, Turner (1964) devised a system of assigning Pasquill stability classes based on hourly surface weather observations. This indirect procedure recognizes that stability in the lower atmospheric layers is primarily dependent upon net radiation and wind speed. Net radiation is estimated as a function of the time of year, the time of day, total cloud cover and cloud ceiling height. Using the surface hourly observations, Turner assigns stability classes assuming that each represents an average for that given hour through the depth in which mixing occurs.

The Pasquill-Turner classification scheme was used in assigning stability classes for each hour of the period of record of surface data from Bismarck, Dickinson, Minot and Williston. This technique is the only means available of obtaining a continuous long-term climatological estimate of stability in the seven county western North Dakota area.

More direct and specific site estimates of atmospheric stability were made from temperature profile sensors located at 10m and 100m heights at the NGPL meteorological study site near Dunn Center from September, 1975 through August, 1976. Pasquill stability classes were assigned from the vertical temperature gradients observed at the tower using the following scheme:

Stability Class	DT/DZ ($^{o}C/100m$)
A	< -1.90
B	-1.70 to -1.90
C	-1.50 to -1.69
D	-0.50 to -1.49
E	1.5 to -0.49
F	> 1.5

Stability Class Frequency

The average monthly and annual percent frequency of each stability class was determined using the Turner classification scheme on the NWS data from Bismarck (1948-1974), Dickinson (1948-1964), Minot (1948-1974) and Williston (1950-1974) and the results are presented in Table 16.

TABLE 16 AVERAGE PERCENT OF TIME IN MONTH AND YEAR WHEN VARIOUS STABILITY CLASSES[1] OCCURRED AT FOUR SELECTED STATIONS IN OR NEAR THE STUDY SITE

		MONTH												
Location	Stability Class	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Bismarck[2]	A	0.0	0.0	0.1	0.0	0.5	0.9	1.2	0.6	0.1	0.0	0.0	0.0	0.3
	B	1.5	2.0	3.8	3.2	3.8	6.0	8.8	6.8	4.2	2.6	0.8	1.5	3.8
	C	6.7	9.4	7.5	8.0	11.9	16.8	17.1	15.2	9.5	7.3	7.5	5.9	10.3
	D	53.6	60.3	63.9	66.5	61.5	53.4	41.1	44.4	51.6	53.2	60.1	59.1	56.1
	E	13.4	10.8	10.4	9.7	9.2	8.7	11.9	12.4	12.8	13.8	12.3	12.5	11.5
	F	19.3	17.5	14.4	12.6	13.1	14.1	19.9	20.6	21.6	23.1	19.4	20.0	18.0
Dickinson[3]	A	0.0	0.0	0.1	0.2	0.6	1.2	1.5	0.9	0.2	0.0	0.0	0.0	0.4
	B	0.3	0.3	1.6	2.2	2.2	4.4	5.7	4.3	1.9	0.9	0.3	0.2	2.0
	C	3.4	4.1	5.2	5.7	10.1	14.1	15.7	11.5	6.4	4.2	2.8	3.5	7.2
	D	78.5	79.4	75.5	74.1	70.6	62.2	51.9	56.6	64.4	67.9	77.7	76.7	69.6
	E	12.2	11.0	10.8	11.9	10.8	10.9	15.3	16.6	16.9	13.0	13.7	13.2	13.5
	F	5.5	5.1	6.8	5.9	5.5	7.2	9.8	10.2	10.2	8.9	5.5	6.3	7.3
Minot[4]	A	0.0	0.0	0.1	0.0	0.7	0.8	1.1	0.5	0.2	0.1	0.0	0.0	0.3
	B	0.7	0.8	2.2	2.2	2.9	4.3	5.9	4.4	2.4	1.4	0.3	0.5	2.3
	C	4.3	5.7	6.1	6.6	10.6	14.0	15.7	12.9	6.7	5.0	3.9	4.5	8.0
	D	73.6	73.6	71.8	72.7	65.7	61.2	49.5	53.2	63.2	65.9	75.2	73.5	66.6
	E	12.3	12.3	12.1	11.7	12.5	12.3	16.6	16.7	16.9	18.0	13.4	13.4	14.0
	F	9.0	7.6	7.7	6.7	7.5	7.4	11.2	12.3	10.6	9.6	7.2	8.2	8.8
Williston[5]	A	0.0	0.0	0.1	0.1	1.0	1.5	2.6	0.7	0.0	0.0	0.0	0.0	0.5
	B	1.5	1.4	5.0	6.0	6.5	10.8	15.1	11.8	6.7	3.9	0.8	1.3	6.0
	C	11.7	15.8	13.8	14.4	19.3	25.3	25.6	24.9	16.0	13.3	11.9	12.6	17.1
	D	56.6	57.0	59.3	63.0	57.5	49.8	36.1	40.0	50.0	50.2	59.3	53.9	52.6
	E	12.3	10.0	9.2	6.7	6.3	5.2	7.1	8.2	10.4	12.7	12.3	13.2	9.4
	F	17.9	15.8	12.6	9.8	9.4	7.4	13.5	14.4	16.8	19.8	15.7	18.9	14.3

[1] As computed from Pasquill-Turner Classification Scheme

[2] 1948-1974

[3] 1948-1964

[4] 1948-1974

[5] 1950-1974

In the Turner stability classification scheme, the occurrence of unstable and stable stability classes is particularly sensitive to lower wind speeds. Accordingly, since the mean monthly and annual wind speeds for Williston and Bismarck are lower than the comparable mean wind speeds for Dickinson and Minot (See Tables 10 through 13), the percent frequency of occurrence of non-neutral stability classes is also higher. On an annual average basis, non-neutral stability conditions occurred 30.4% of the time (1948-1964) at Dickinson while they occurred 47.4% of the time (1950-1974) at Williston. This comparison points-out that from surface wind observations, it may be deduced that small, but significant differences in stability class assignments for diffusion modelling exists between different points of observation in the study area.

The seasonal trends of stability among the four stations are more closely similar. The unstable stability classes, A, B, and C, increase to a maximum frequency in July of 22.9% (of the time) in Dickinson and 43.3% in Williston. The frequencies of neutral conditions are highest for the months with the highest mean wind speeds, ranging from 79.4% in February at Dickinson to a high of 59.3% in March at Williston. Stable conditions, E and F stabilities, are most frequent in September and October at the four locations ranging from a frequency of 27.1% in September at Dickinson to 32.5% in October at Williston.

On an annual basis, the very unstable A stability class occurs on the average, only 0.3% to 0.5% of the time in the study area. This frequency however, is sufficiently significant to be considered in atmospheric dispersion models, especially for short-term modeling. The annual average frequencies of the stable E and F range in value from 20.8% at Dickinson to 29.5% at Bismarck. The frequencies of E and F stability classes are a fair index of the occurrence of radiation inversions which tend to inhibit vertical mixing through the inversion layer.

The monthly and annual percent frequencies of recurrence of each stability class were determined from delta temperature (ΔT) values observed at the NDSU tower at Dunn Center. The stability categories derived for the NGPL study and given earlier in this report were used and the results are presented in Table 17.

TABLE 17 FREQUENCIES OF OCCURRENCES OF STABILITY CLASSES CALCULATED FROM DATA COLLECTED NEAR DUNN CENTER FROM SEPTEMBER, 1975 THROUGH AUGUST, 1976

Month	Percent of Time in Month When Stability Class Occurred					
	A	B	C	D	E	F
1976						
January	0.0	0.0	0.0	18.2	41.7	40.2
Feburary	0.0	0.1	0.4	39.2	34.3	26.0
March	0.1	0.8	2.0	44.5	25.2	27.4
April	0.4	1.4	5.4	47.9	18.9	26.0
May	6.2	1.5	3.6	42.2	14.8	31.7
June	1.2	1.9	3.8	45.8	24.5	22.9
July	0.5	4.2	9.1	34.0	21.1	31.2
August	0.7	2.4	7.9	33.3	25.4	30.3
1975						
September	0.6	1.9	7.9	37.9	18.5	33.2
October	0.0	0.7	1.5	44.8	23.4	29.5
November	0.0	0.1	0.4	38.0	20.3	41.3
December	0.0	0.0	0.0	30.5	32.3	37.2
1-year Average	0.8	1.2	3.5	37.8	25.2	31.6

[1] computed using DT/DZ tower data

The frequencies of stability classes computed using temperature profile data from the NDSU tower are not comparable to data obtained from the Turner stability classification listing surface weather data. Since the actual temperature profile is a more direct measure of stability and is measured through at least the lower portion of the mixing layer of the atmosphere, the Dunn Center data is considered more representative of the true stability conditions in the Dunn Center area than that determined from surface weather data. However, the surface data from the four NWS stations represent at least four points in the study area and are for a longer period of time.

Table 17 shows that unstable conditions (stability classes A, B, and C) at the NGPL study site were most frequent in the summer months, 13.8% of the time in July and did not occur at all in December or January. Stable conditions existed 81.9% of the time in January but only 44.9% in April. Neutral conditions, D stability, occurred consistently between 30% and 50% throughout the year, except January, when they occurred less than 20% of the time. The 6.2% frequency of the very unstable A stability in May reflects a few unusually hot and dry (between 10% and 20% relative humidity) days and probably does not represent the average condition for May.

Wind Roses by Stability Classes

The relative frequency distributions of wind speed/wind direction according to stability class (WS/WD by SC) were calculated for the entire period of record from the surface weather data available for the NWS stations, Bismarck, Dickinson, Minot and Williston. These distributions serve as direct data input into the UNAMAP climatological dispersion model. The annual average WS/WD by SC for Bismarck from 1948-1974 is given in Table 18. The method of calculation of these wind roses for each stability class and a listing of those prepared as a part of this report are described in Chapter III. A similar summary from tower wind and temperature profile data collected at Dunn Center from September, 1975 through August, 1976 is presented in Table 19. A comparison between Table 18 and 19 shows the same differences noted between the two data sources in the previous discussions of wind roses and stability class frequencies. Similarly, a comparison among the four NWS stations' stability class wind roses show similar differences described earlier.

In addition to providing the meteorological data input for long-term dispersion modeling, the stability class/wind rose calculations contain information relevant to short-term modeling. For example, if A stability and light winds have been determined to result in worst case pollutant concentrations at ground level for a particular set of source conditions near Bismarck, a quick glance at Table 18 would show that these meteorological conditions occurred only 0.3% of the time over a 27 year period. The prevailing wind direction of these 'worst-case' meteorological conditions can also be determined from the table.

TABLE 18 PERCENT FREQUENCIES OF WIND SPEED/WIND DIRECTION COMBINATIONS FOR EACH STABILITY CLASS IN BISMARCK (1948-1974)

Stability Class	Direction	Wind Speed (Knots)						
		0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	> 21	Total
A	N	0.000056	0.000034	0.000000	0.000000	0.000000	0.000000	0.000090
A	NNE	0.000051	0.000095	0.000000	0.000000	0.000000	0.000000	0.000145
A	NE	0.000062	0.000051	0.000000	0.000000	0.000000	0.000000	0.000113
A	ENE	0.000137	0.000095	0.000000	0.000000	0.000000	0.000000	0.000232
A	E	0.000129	0.000084	0.000000	0.000000	0.000000	0.000000	0.000213
A	ESE	0.000080	0.000073	0.000000	0.000000	0.000000	0.000000	0.000153
A	SE	0.000090	0.000135	0.000000	0.000000	0.000000	0.000000	0.000225
A	SSE	0.000073	0.000112	0.000000	0.000000	0.000000	0.000000	0.000185
A	S	0.000096	0.000112	0.000000	0.000000	0.000000	0.000000	0.000208
A	SSW	0.000079	0.000067	0.000000	0.000000	0.000000	0.000000	0.000146
A	SW	0.000152	0.000101	0.000000	0.000000	0.000000	0.000000	0.000253
A	WSW	0.000135	0.000124	0.000000	0.000000	0.000000	0.000000	0.000259
A	W	0.000163	0.000107	0.000000	0.000000	0.000000	0.000000	0.000270
A	WNW	0.000157	0.000135	0.000000	0.000000	0.000000	0.000000	0.000292
A	NW	0.000101	0.000051	0.000000	0.000000	0.000000	0.000000	0.000152
A	NNW	0.000045	0.000056	0.000000	0.000000	0.000000	0.000000	0.000101
B	N	0.000557	0.000561	0.000231	0.000000	0.000000	0.000000	0.001349
B	NNE	0.000376	0.000371	0.000185	0.000000	0.000000	0.000000	0.000932
B	NE	0.000657	0.000421	0.000219	0.000000	0.000000	0.000000	0.001297
B	ENE	0.001263	0.000601	0.000264	0.000000	0.000000	0.000000	0.002128
B	E	0.001455	0.000573	0.000330	0.000000	0.000000	0.000000	0.002358
B	ESE	0.001252	0.000792	0.000589	0.000000	0.000000	0.000000	0.002633
B	SE	0.001168	0.000736	0.000538	0.000000	0.000000	0.000000	0.002442
B	SSE	0.000998	0.000904	0.000608	0.000000	0.000000	0.000000	0.002510
B	S	0.000848	0.001162	0.000732	0.000000	0.000000	0.000000	0.002742
B	SSW	0.000999	0.001022	0.000775	0.000000	0.000000	0.000000	0.002796
B	SW	0.001039	0.001005	0.000472	0.000000	0.000000	0.000000	0.002515
B	WSW	0.001308	0.001252	0.000556	0.000000	0.000000	0.000000	0.003116
B	W	0.001752	0.001314	0.000668	0.000000	0.000000	0.000000	0.003734
B	WNW	0.001252	0.001331	0.000741	0.000000	0.000000	0.000000	0.003324
B	NW	0.000747	0.000629	0.000556	0.000000	0.000000	0.000000	0.001932
B	NNW	0.000561	0.000601	0.000404	0.000000	0.000000	0.000000	0.001567
C	N	0.000494	0.000983	0.001707	0.000539	0.000118	0.000006	0.003846
C	NNE	0.000432	0.000353	0.001095	0.000314	0.000097	0.000000	0.002763
C	NE	0.000590	0.000960	0.000948	0.000219	0.000023	0.000000	0.002740
C	ENE	0.001337	0.002223	0.001651	0.000359	0.000045	0.000006	0.005620
C	E	0.001539	0.003033	0.002039	0.000365	0.000112	0.000005	0.007093
C	ESE	0.001253	0.002549	0.002437	0.000522	0.000140	0.000024	0.006940
C	SE	0.000932	0.002240	0.002684	0.000501	0.000208	0.000039	0.006704
C	SSE	0.000747	0.002055	0.003773	0.001465	0.000433	0.000118	0.008591
C	S	0.000713	0.002167	0.003156	0.001034	0.000325	0.000052	0.007537
C	SSW	0.000629	0.001814	0.002970	0.000819	0.000112	0.000017	0.006350
C	SW	0.000932	0.002145	0.002184	0.001443	0.000223	0.000006	0.006933
C	WSW	0.001342	0.002392	0.002746	0.001347	0.000113	0.000017	0.007957
C	W	0.001701	0.003172	0.002943	0.000573	0.000225	0.000051	0.008675
C	WNW	0.001319	0.003235	0.004359	0.001034	0.000460	0.000153	0.010576
C	NW	0.000691	0.001791	0.003155	0.000933	0.000371	0.000101	0.007047
C	NNW	0.000472	0.001084	0.002252	0.000837	0.000348	0.000095	0.005088
D	N	0.000758	0.001960	0.008883	0.014655	0.004756	0.001005	0.032016
D	NNE	0.000343	0.001096	0.003080	0.013547	0.002504	0.000453	0.021023
D	NE	0.001252	0.002128	0.006727	0.006339	0.001069	0.000623	0.018138
D	ENE	0.001573	0.003565	0.013099	0.010052	0.003262	0.000758	0.032309
D	E	0.002223	0.004345	0.017193	0.015368	0.004352	0.001039	0.044520
D	ESE	0.001595	0.003543	0.013425	0.013914	0.004127	0.001241	0.037845
D	SE	0.001218	0.002393	0.012229	0.013565	0.004093	0.000971	0.034475
D	SSE	0.000933	0.002533	0.012751	0.022920	0.003243	0.001830	0.044135
D	S	0.000965	0.001971	0.006733	0.012021	0.003504	0.000517	0.025710
D	SSW	0.000730	0.001483	0.005166	0.006103	0.001129	0.000224	0.014835
D	SW	0.000666	0.001460	0.004514	0.004155	0.000590	0.000134	0.011769
D	WSW	0.001028	0.001815	0.005361	0.005110	0.001105	0.000354	0.014773
D	W	0.001392	0.002263	0.010917	0.011134	0.004566	0.000121	0.030394
D	WNW	0.001544	0.003332	0.012931	0.029113	0.014641	0.000715	0.062277
D	NW	0.001174	0.002156	0.011403	0.030315	0.017951	0.009523	0.072506
D	NNW	0.000837	0.001842	0.009828	0.024324	0.012983	0.004539	0.054352
E	N	0.000000	0.001522	0.002263	0.000000	0.000000	0.000000	0.003784
E	NNE	0.000000	0.001297	0.001353	0.000000	0.000000	0.000000	0.002650
E	NE	0.000000	0.002044	0.002950	0.000000	0.000000	0.000000	0.004994
E	ENE	0.000000	0.005223	0.006011	0.000000	0.000000	0.000000	0.011234
E	E	0.000000	0.009294	0.003985	0.000000	0.000000	0.000000	0.013279
E	ESE	0.000000	0.005599	0.004211	0.000000	0.000000	0.000000	0.009810
E	SE	0.000000	0.003702	0.003276	0.000000	0.000000	0.000000	0.006978
E	SSE	0.000000	0.002582	0.004745	0.000000	0.000000	0.000000	0.007327
E	S	0.000000	0.002094	0.002358	0.000000	0.000000	0.000000	0.004453
E	SSW	0.000000	0.001598	0.002339	0.000000	0.000000	0.000000	0.003937
E	SW	0.000000	0.001943	0.002223	0.000000	0.000000	0.000000	0.004166
E	WSW	0.000000	0.003172	0.002425	0.000000	0.000000	0.000000	0.005597
E	W	0.000000	0.002931	0.003409	0.000000	0.000000	0.000000	0.006340
E	WNW	0.000000	0.003594	0.009843	0.000000	0.000000	0.000000	0.013437
E	NW	0.000000	0.002364	0.006991	0.000000	0.000000	0.000000	0.009355
E	NNW	0.000000	0.001465	0.002942	0.000000	0.000000	0.000000	0.004408
F	N	0.003431	0.001752	0.000000	0.000000	0.000000	0.000000	0.005183
F	NNE	0.003178	0.001392	0.000000	0.000000	0.000000	0.000000	0.004570
F	NE	0.005205	0.002740	0.000000	0.000000	0.000000	0.000000	0.007945
F	ENE	0.009708	0.003321	0.000000	0.000000	0.000000	0.000000	0.013029
F	E	0.011353	0.009512	0.000000	0.000000	0.000000	0.000000	0.020865
F	ESE	0.007315	0.007138	0.000000	0.000000	0.000000	0.000000	0.014453
F	SE	0.006727	0.005334	0.000000	0.000000	0.000000	0.000000	0.012061
F	SSE	0.005942	0.003290	0.000000	0.000000	0.000000	0.000000	0.009232
F	S	0.004865	0.002434	0.000000	0.000000	0.000000	0.000000	0.007299
F	SSW	0.003925	0.002223	0.000000	0.000000	0.000000	0.000000	0.006148
F	SW	0.006345	0.003448	0.000000	0.000000	0.000000	0.000000	0.009792
F	WSW	0.009214	0.006845	0.000000	0.000000	0.000000	0.000000	0.016059
F	W	0.010006	0.007400	0.000000	0.000000	0.000000	0.000000	0.017406
F	WNW	0.008414	0.006435	0.000000	0.000000	0.000000	0.000000	0.014849
F	NW	0.005722	0.004009	0.000000	0.000000	0.000000	0.000000	0.009731
F	NNW	0.004003	0.001774	0.000000	0.000000	0.000000	0.000000	0.005778

TABLE 19 PERCENT FREQUENCIES OF WIND SPEED/WIND DIRECTION COMBINATIONS FOR EACH STABILITY CLASS AT DUNN CENTER, NORTH DAKOTA (SEPTEMBER, 1975-AUGUST, 1976)

Stability Class	Wind Direction	Wind Speed (MPH) 1 - 3	4 - 7	8 - 11	12 - 17	18 - 22	> 22	Total
A	N	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0003
A	NNE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
A	NE	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0003
A	ENE	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0002
A	E	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
A	ESE	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0002
A	SE	0.0000	0.0000	0.0001	0.0016	0.0002	0.0003	0.0022
A	SSE	0.0000	0.0000	0.0004	0.0013	0.0004	0.0008	0.0029
A	S	0.0000	0.0000	0.0003	0.0005	0.0001	0.0000	0.0009
A	SSW	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
A	SW	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A	WSW	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A	W	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
A	WNW	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
A	NW	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0004
A	NNW	0.0000	0.0000	0.0001	0.0006	0.0000	0.0000	0.0007
B	N	0.0000	0.0000	0.0001	0.0001	0.0002	0.0001	0.0004
B	NNE	0.0000	0.0001	0.0000	0.0002	0.0001	0.0001	0.0004
B	NE	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001
B	ENE	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
B	E	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B	ESE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
B	SE	0.0000	0.0000	0.0000	0.0004	0.0003	0.0009	0.0015
B	SSE	0.0000	0.0000	0.0002	0.0006	0.0011	0.0010	0.0028
B	S	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0003
B	SSW	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0003
B	SW	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003
B	WSW	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0003
B	W	0.0000	0.0001	0.0001	0.0002	0.0001	0.0004	0.0008
B	WNW	0.0000	0.0000	0.0001	0.0004	0.0010	0.0002	0.0017
B	NW	0.0000	0.0001	0.0000	0.0005	0.0011	0.0004	0.0021
B	NNW	0.0000	0.0000	0.0000	0.0003	0.0003	0.0000	0.0006
C	N	0.0000	0.0001	0.0005	0.0007	0.0010	0.0003	0.0027
C	NNE	0.0000	0.0002	0.0003	0.0011	0.0003	0.0001	0.0019
C	NE	0.0000	0.0001	0.0003	0.0010	0.0001	0.0001	0.0015
C	ENE	0.0000	0.0000	0.0003	0.0002	0.0001	0.0002	0.0007
C	E	0.0000	0.0000	0.0001	0.0007	0.0001	0.0001	0.0010
C	ESE	0.0000	0.0001	0.0001	0.0003	0.0003	0.0001	0.0008
C	SE	0.0000	0.0001	0.0001	0.0005	0.0013	0.0008	0.0028
C	SSE	0.0000	0.0000	0.0002	0.0015	0.0021	0.0014	0.0052
C	S	0.0000	0.0000	0.0001	0.0013	0.0006	0.0001	0.0021
C	SSW	0.0000	0.0000	0.0001	0.0001	0.0006	0.0001	0.0009
C	SW	0.0000	0.0000	0.0001	0.0002	0.0002	0.0000	0.0005
C	WSW	0.0000	0.0000	0.0000	0.0003	0.0002	0.0000	0.0004
C	W	0.0000	0.0001	0.0000	0.0007	0.0003	0.0003	0.0013
C	WNW	0.0000	0.0000	0.0003	0.0012	0.0013	0.0003	0.0031
C	NW	0.0000	0.0001	0.0002	0.0020	0.0015	0.0011	0.0049
C	NNW	0.0000	0.0001	0.0004	0.0013	0.0011	0.0004	0.0033
D	N	0.0000	0.0037	0.0091	1.0003	0.0057	0.0019	3.0007
D	NNE	0.0001	0.0031	0.0053	0.0078	0.0019	0.0025	2.0007
D	NE	0.0006	0.0019	0.0048	0.0066	0.0031	0.0016	1.0095
D	ENE	0.0001	0.0021	0.0024	0.0062	0.0029	0.0004	1.0041
D	E	0.0005	0.0024	0.0041	0.0086	0.0033	0.0011	2.0000
D	ESE	0.0003	0.0015	0.0051	0.0060	0.0012	0.0004	1.0046
D	SE	0.0003	0.0026	0.0042	0.0092	0.0033	0.0015	2.0011
D	SSE	0.0002	0.0021	0.0066	1.0053	0.0050	0.0023	3.0015
D	S	0.0003	0.0023	0.0046	0.0078	0.0024	0.0004	1.0079
D	SSW	0.0001	0.0022	0.0035	0.0045	0.0013	0.0003	1.0020
D	SW	0.0003	0.0028	0.0037	0.0046	0.0012	0.0003	1.0028
D	WSW	0.0003	0.0022	0.0042	0.0047	0.0011	0.0005	1.0030
D	W	0.0003	0.0035	0.0053	1.0013	0.0043	0.0025	2.0072
D	WNW	0.0001	0.0017	0.0042	1.0008	0.0092	0.0076	3.0037
D	NW	0.0003	0.0033	0.0085	2.0018	1.0004	1.0001	5.0044
D	NNW	0.0001	0.0033	0.0067	1.0044	0.0068	0.0052	3.0085
E	N	0.0003	0.0025	0.0041	0.0033	0.0010	0.0003	1.0016
E	NNE	0.0001	0.0023	0.0024	0.0017	0.0006	0.0002	0.0073
E	NE	0.0003	0.0024	0.0024	0.0026	0.0006	0.0003	0.0034
E	ENE	0.0001	0.0011	0.0010	0.0018	0.0013	0.0001	0.0055
E	E	0.0003	0.0021	0.0026	0.0049	0.0011	0.0004	1.0014
E	ESE	0.0003	0.0015	0.0024	0.0048	0.0024	0.0004	1.0018
E	SE	0.0003	0.0029	0.0033	0.0040	0.0017	0.0021	1.0043
E	SSE	0.0004	0.0039	0.0049	0.0055	0.0017	0.0008	1.0073
E	S	0.0003	0.0041	0.0044	0.0037	0.0012	0.0003	1.0039
E	SSW	0.0006	0.0027	0.0026	0.0017	0.0006	0.0001	0.0084
E	SW	0.0009	0.0035	0.0016	0.0030	0.0003	0.0000	1.0013
E	WSW	0.0006	0.0035	0.0037	0.0042	0.0010	0.0001	1.0031
E	W	0.0010	0.0063	0.0069	1.0023	0.0041	0.0017	3.0024
E	WNW	0.0007	0.0048	0.0068	1.0007	0.0048	0.0062	3.0040
E	NW	0.0004	0.0036	0.0079	1.0012	0.0045	0.0078	3.0053
E	NNW	0.0005	0.0028	0.0046	0.0049	0.0022	3.0014	1.0064
F	N	0.0004	0.0013	0.0022	0.0010	0.0001	0.0000	0.0051
F	NNE	0.0007	0.0012	0.0011	0.0010	0.0001	0.0000	0.0040
F	NE	0.0006	0.0015	0.0015	0.0013	0.0003	0.0000	0.0053
F	ENE	0.0004	0.0011	0.0017	0.0021	0.0012	0.0001	0.0065
F	E	0.0010	0.0022	0.0033	0.0032	0.0013	0.0003	1.0014
F	ESE	0.0013	0.0022	0.0033	0.0019	0.0008	0.0001	0.0099
F	SE	0.0021	0.0053	1.0007	0.0062	0.0015	0.0013	2.0070
F	SSE	0.0018	1.0044	1.0014	0.0044	0.0008	0.0004	3.0032
F	S	0.0047	1.0007	0.0085	0.0064	0.0011	0.0002	3.0016
F	SSW	0.0034	0.0076	0.0013	0.0045	0.0001	0.0002	1.0056
F	SW	0.0042	0.0091	0.0054	0.0037	0.0003	0.0001	2.0029
F	WSW	0.0055	1.0029	0.0087	0.0060	0.0005	0.0001	3.0037
F	W	0.0067	2.0037	1.0063	1.0033	0.0023	0.0025	5.0075
F	WNW	0.0024	0.0011	0.0066	0.0049	0.0014	0.0008	2.0041
F	NW	0.0017	0.0037	0.0039	0.0037	0.0010	0.0006	1.0046
F	NNW	0.0006	0.0022	0.0033	0.0013	0.0003	0.0000	0.0077

Stability Classes by Hour of the Day

Since atmospheric stability in the lowest kilometer is dependent upon net radiation, the difference between incoming and outgoing components of solar and terrestial radiation, the frequency of occurrence of each stability class depends on the time of day. In many foreseeable short-term dispersion modeling problems, such as, short-term, non-continuous, time-dependent or instantaneous pollutant releases, information on the frequency of occurrence of the stability classes for a particular time of day could be valuable in determining applicable meteorological conditions for modeling. The monthly and annual average frequencies of each stability class by hour of day were determined from all available NWS surface hourly observation data for Bismarck, Dickinson, Minot, and Williston. The percent frequencies of occurrence of each stability for all hours of the day from 1948-1964 at Bismarck is graphed in Figure 17. Stability classes by hour of the day for all four stations are included in computer printout format as Attachment 6 to this report.

Figure 17 shows that D stability condition occurred most frequently among all stability classes at all hours of the day. This condition peaked 75% of the time at 1600 CST and was lowest, near 45% of the time during the early morning hours. The D stability conditions occur in the absence of nighttime radiation inversions or intense solar radiation at the surface.

The stable E and F conditions were most frequent during the nighttime hours, the F stability most frequent at 4 a.m. CST and E stability

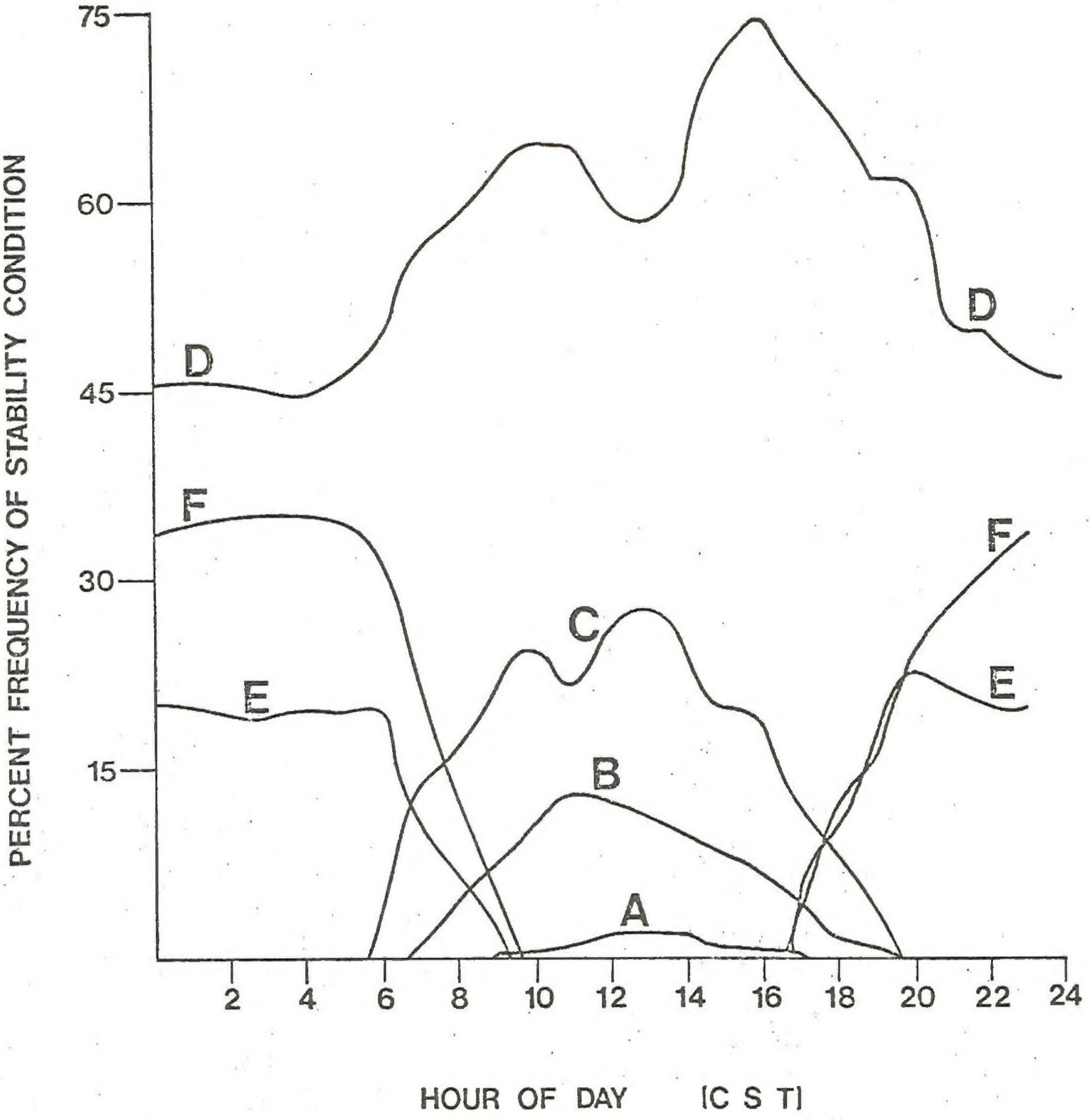


Figure 17. Stability Class Frequency By Hour of the Day at Bismarck 1943-1974

conditions at 8 p.m. CST. By definition, stable conditions do not occur in the sunlight hours.

Unstable conditions were most frequent in the early afternoon hours, with C stability occurring 28% of the time at 1300 CST, B stability (13% of the time) at 1100 CST and A stability (2% of the time) at 1300 CST. Unstable conditions are dependent on solar radiation according to the Pasquill-Turner stability classification scheme, and therefore, are not expected in the nighttime hours.

The stability-class-by-hour-of-the-day data for the other three stations (Minot, Williston and Dickinson) are available in the computer printouts attached to this report (Attachment 6). The diurnal trends of atmospheric stability differed very slightly among the four stations.

The results of the analyses of the diurnal tendencies of stability class frequencies for the one-year period of tower data at Dunn Center are depicted in Figure 18. The differences that may be discerned between Figure 17 and 18 can be traced to the different stability class computational techniques. The percent frequencies of the D stability conditions from the tower profile data during nighttime hours are much lower than those at Bismarck calculated using the Turner method. The diurnal trends for the unstable and stable conditions are very similar for the two data sources.

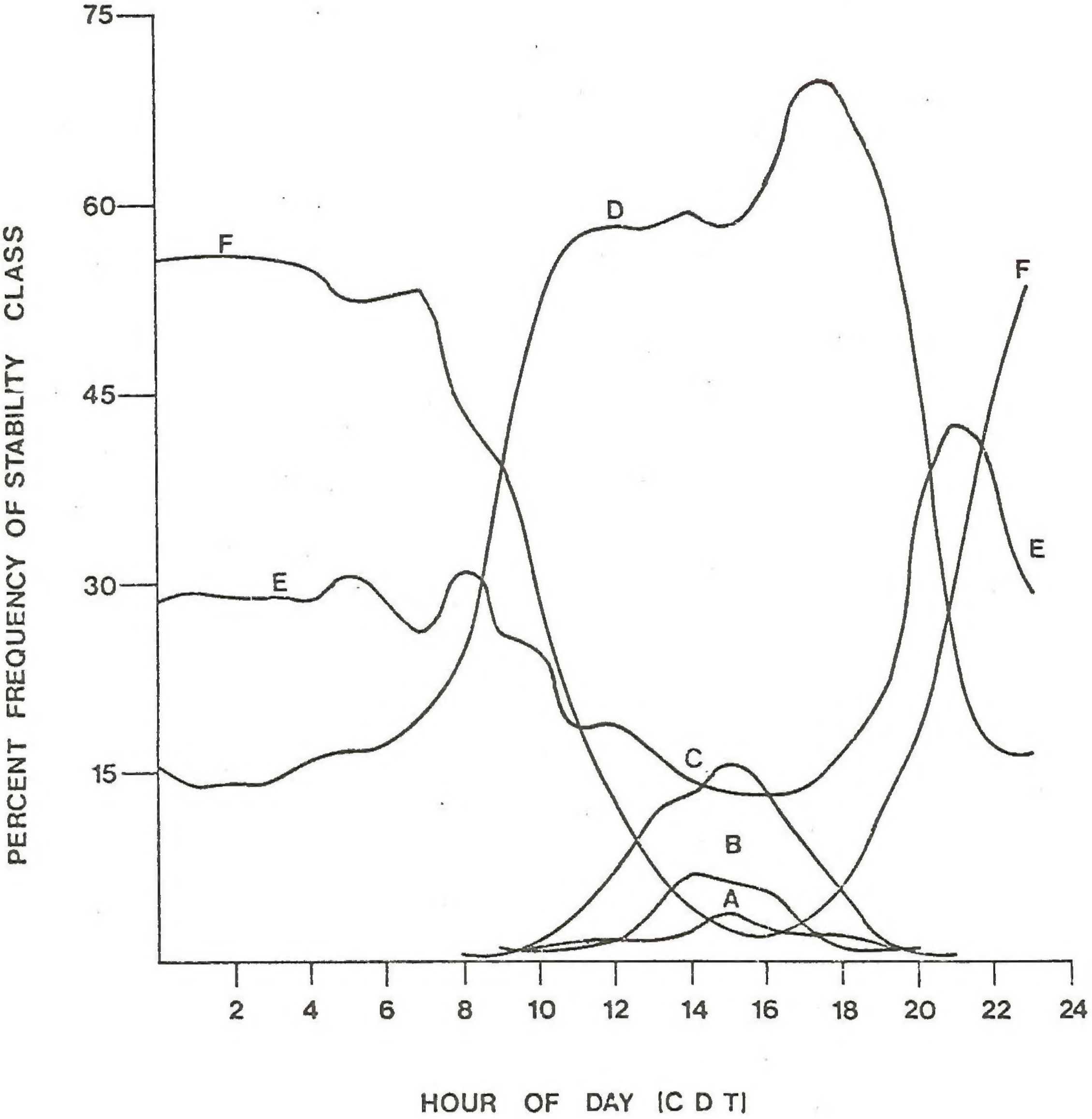


Figure 18. Stability Class Frequency By Hour of the Day for September, 1975 Through August, 1976 at Dunn Center

The Persistence of Stability Classes

When drawing comparisons between the estimates of ground-level pollutant concentrations by short-term dispersion models and the existing 3-, 8-, and 24-hour state and federal air quality standards, the persistence of the modeled worst-case meteorological conditions for these time periods should be known. Accordingly, the persistence of Pasquill-Turner stability classes for several duration intervals were computed for Bismarck, Dickinson, Minot and Williston. These analyses included the average monthly and annual frequencies of occurrence of each duration interval, the average duration, and the maximum duration for the period of record, (1948-1964). The results of these analyses for the Bismarck station are given in Table 19. The results for all four stations are included as Attachment 6 to this report in computer printout format.

There is little difference in the persistence of stability classes noted among the four stations. The shorter average duration of D stability and slightly longer persistence of unstable conditions at Williston can be attributed to the lower mean wind speeds recorded at this location.

The summary data given in Table 20 show that the unstable stability classes never occurred for more than 11 consecutive hours between 1948 and 1964 at Bismarck, and A stability conditions never persisted for more than six hours. On the average, A, B and C stabilities persist for less than two hours. Only 1.1% of the B stability classes and 1.6%

TABLE 20 AVERAGE JANUARY, JULY AND ANNUAL STABILITY CLASS PERSISTENCE FOR SEVERAL DURATION INTERVALS FROM NWS BISMARCK DATA, 1948-1964

Stability Class	% Freq. of Occurrence-Duration (Hrs.) 1 - 3	4 - 6	7 - 12	> 12	Average Duration (Hrs)	Maximum Duration (Hrs)
				January, 1948-1964		
A	0.0	0.0	0.0	0.0	0.0	0
B	92.6	7.4	0.0	0.0	1.6	5
C	91.0	9.0	0.0	0.0	1.8	6
D	55.9	13.6	11.6	19.0	8.0	119
E	93.0	6.0	0.8	0.1	1.7	16
F	71.1	16.1	10.6	2.3	3.1	17
				July, 1948-1964		
A	99.1	0.9	0.0	0.0	1.3	4
B	87.5	10.7	1.8	0.0	1.9	11
C	91.4	8.0	0.6	0.0	1.9	8
D	65.3	17.2	10.8	5.6	4.0	60
E	92.9	6.0	1.1	0.0	1.7	10
F	69.0	14.3	16.7	0.0	3.3	11
				Annual, 1948-1964		
A	98.7	1.3	0.0	0.0	1.3	6
B	87.8	10.6	1.6	0.0	1.9	11
C	90.0	9.0	1.1	0.0	1.9	10
D	57.1	15.1	12.8	15.1	7.2	194
E	92.1	7.0	0.9	0.0	1.7	16
F	68.4	15.2	14.1	2.4	3.4	17

of C stability occurrences persisted for more than six hours. About 90% of all unstable condition occurrences lasted between one and three hours. Both the frequency and duration of unstable conditions are greater in July than in January.

Neutral D stability conditions, occurred for more than 12 hours 15% of the time and had a maximum duration of over eight days (192 hours) during one December. The average duration of D stability is longer in the winter months (eight hours in January) than during the warmer months, (four hours in July). Unstable conditions frequently occur instead of neutral stability during summer afternoons.

The stable E and F classes were generally of short duration throughout the year. F stability class, however, frequently persisted for more than six hours and lasted a maximum of 17 hours in December. In the Pasquill-Turner stability classification scheme, E and F stabilities are limited to the nighttime hours. The computer printouts of the stability class persistence data for the four NWS stations (Attachment 6) give the number of occurrences and not the percent frequency of occurrence of each stability class events over the indicated period of record for each duration interval.

The results of dispersion modeling change radically with wind direction, even if the atmospheric stability remains the same. For this reason, information on the persistence of stability class by wind direction is advisable. The upper limits of this frequency can be determined from the analyses of wind speed/wind direction-by-stability class discussed previously. For example, if A stability persisted for a maximum of six hours in June, the relative frequencies given in the wind rose for this stability class and for each wind direction will show whether or not A stability existed for six hours from any or all wind directions. If it did, A stability and the corresponding direction can be modeled for the six-hour period, as a worst case condition.

The computer printouts presented in Attachment 3 offers information for determining appropriate short-term and worst-case short-term meteorological conditions for dispersion modeling for any combination of months or as an annual average.

The frequencies of stability class durations for several duration intervals from Dunn Center data collected between September, 1975 and August, 1976 is presented in Table 21.

TABLE 21 FREQUENCIES OF STABILITY CLASS DURATIONS[1] FOR SEVERAL INTERVALS AT DUNN CENTER FROM SEPTEMBER, 1975 THROUGH AUGUST, 1976

	% Frequency of Occurrence-Duration[2] (Hrs.)					
	Percent of Time				Average	Maximum
Class	0.5-3.0%	3.5-6.0%	6.5-12.0%	> 12.0%	Duration	Duration
A	81.3	12.5	6.3	0.0	2.1	9.0
B	98.2	1.8	0.0	0.0	0.9	4.0
C	98.6	1.4	0.0	0.0	1.1	4.5
D	52.2	24.4	16.0	7.5	4.8	84.5
E	76.8	14.1	8.1	0.1	2.4	28.0
F	48.4	12.5	26.3	12.7	5.6	24.0

[1] Based on DT/DZ 10-100m Data

[2] Based on half-hour averages

The table shows that no unstable condition persisted longer than 9.0 hours for the year at Dunn Center. Both E and F stabilities occurred for 24 hours and over and neutral conditions continued for three consecutive days in late February and early March.

Temperature Inversions

A temperature inversion is defined as an increase in temperature-with-height. This stable condition generally restricts vertical and horizontal dispersal of pollutants and, if existing aloft, can act as a lid to vertical diffusion thus trapping pollutants beneath. Surface-based diurnal inversions are usually caused by radiational cooling of the ground during nighttime hours. Upper-air inversions are often associated with subsidence or descending air, common to large-scale anticyclones, and with frontal inversions which occur ahead of surface warm and cold fronts. Whatever the cause, an inversion layer represents poor dispersion conditions. The severity of the conditions is dependent upon the location of the inversion base, its intensity and thickness and the characteristics of pollutant source.

The rawinsonde soundings of temperature and wind taken daily at Bismarck at 1200 GMT (Greenwich Mean Time) and 0000 GMT are the only available long-term data from which inversions through the first kilometer of the atmosphere can be characterized. Holzworth (1974) analyzed these soundings from all NWS rawinsonde stations in the U.S., including Bismarck, for several features of inversions through the lowest 3000m of the atmosphere. Holzworth defined an inversion as any layer through which the temperature remains the same (isothermal) or increases with height, that is, $DT/DZ \geqq 0$. This inversion study noted the percent frequencies of the occurrences of heights, thicknesses, intensities, and lapse rates of the bases of inversions aloft. The height of the inversion base is the level at which an inversion layer begins. Inversion thickness is the depth of the inversion layer and the intensity is the rate at which temperature increases with height, DT/DZ.

Table 22 summarizes the seasonal and annual frequencies of inversion thicknesses and intensities at Bismarck, at 1200 GMT and 0000 GMT according to the data from 1960-1964. The frequencies of implied fumigation potential conditions are also included in the table. Fumigation exists when pollutants, previously emitted into a stable layer, spread vertically toward the ground as a surface-based nighttime radiation inversion progresses to a neutral condition through the plume top due to increasing solar heating after sunrise. These conditions frequently result in high pollutant ground level concentrations. The fumigation potential frequencies given in Table 22 are based on a $DT/DZ < -1.14^{\circ}C/100m$ below an inversion based between 1m and 500m heights.

Table 22 presents a description of the occurrences of radiation inversions in early morning (1200z, 6:00 a.m. CST) and early evening (0000z or 6:00 p.m. CST) hours at Bismarck. On an annual basis, inversions at 1200z were found in 91.6% of the soundings based somewhere in the first 1000m. In 64.3% of the soundings, surface-based inversions were noted with 72% of these inversions having a thickness less than

500 meters. About 2/3 of the surface-based inversions had relatively strong intensities with a lapse rate $DT/DZ < 1.14^{\circ}C/100m$. Surface based inversions were most frequent in the summer when they were noted to occur 79% of the time.

TABLE 22 PERCENT OF TIME WHEN INVERSIONS OF GIVEN THICKNESSES AND INTENSITIES OCCUR IN BISMARCK (BASED ON RAWINSONDE DATA FROM 1960-1964)

	Percent of Time When Inversion[1] Occurred				
Category	Dec-Feb.	Mar-May	Jun-Aug.	Sept-Nov.	Annual
		1200 Z			
Sfc. Based Inversion	51.9%	53.3%	78.9%	73.2%	64.3%
Inv. Based 1-500m	29.8	21.6	11.2	9.4	18.0
Inv. Based 501-1000m	13.5	11.0	4.6	7.9	9.3
Total Inv. Sfc-1000m	95.2	85.9	94.7	90.5	91.6
Sfc. Based-Thickness < 500m	21.1	37.8	62.0	57.5	43.2
Sfc. Based-Intensity > 1.14°C/100m	30.1	32.1	52.5	51.5	45.1
Fumigation Potential[2]	7.1	3.8	0.6	0.6	3.1
		0000Z			
Sfc. Based Inversion	23.8	1.5	1.8	13.7	10.2
Inv. Based 1-500m	34.4	7.7	1.3	4.4	12.1
Inv. Based 501-1000m	24.7	14.5	3.8	17.3	15.0
Total Inv Sfc-100m	81.9	23.7	6.9	35.4	37.3
Sfc. Based-Thickness < 500m	14.4	1.3	1.6	11.3	7.3
Sfc. Based-Intensity > 1.14°C/100m	10.0	0.0	0.2	6.3	4.3
Fumigation Potential[2]	7.5	3.2	1.0	0.9	3.3

[1] Inversion is any layer with $DT/DZ \geq 0.0^{\circ}C/100m$

[2] Fumigation Potential - $DT/DZ < -1.21^{\circ}C/100m$ below inversion layer based between surface and 500 m

Source: Inversion Study for Bismarck, NCC (Holzworth, 1974)

However, when those occurring aloft are included, the total number of inversions through the lowest kilometer were most frequent during the winter months, when they occurred 92.5% of the time. During the five-year period studied, fumigation potential conditions existed 3.1% of the time at 1200z. These conditions occurred most frequently (7.1%) from December through February, decreasing to 0.6% of the time from June through November. These frequencies of potential fumigation conditions compares favorably to a 3-4% figure estimated by Crawford (1976) from tower profile data collected at Hannover and Dickinson.

Almost all inversions measured at 1200z are nighttime occurrences. At 0000z or 6 p.m. CST, the surface based inversions occur only 10.2% of the time on an annual average. Most of these inversions occurred in the cooler months, September through February, reflecting the start of nighttime radiation inversions during months of long nights. Otherwise, inversions were found in the lowest 1000m only 6.9% of the time during the summer at 0000z. These inversions were rarely more intense than 1.14°C/100m nor had thicknesses greater than 500m.

A continuous monitoring of inversion occurrences in the first 100m of the atmosphere is available from the temperature profile data at Dunn Center. An inversion occurrence was defined (Crawford, 1976) as an increase of temperature greater than or equal to 1°C/100m through the tower depth. The tower profile data reflect the diurnal and seasonal cycles of radiation inversions. The percent of time during September, 1975 through August, 1976 when inversion conditions at the site were noted are given in Table 23. The percent frequency of

TABLE 23 PERCENT OF TIME DURING WHICH INVERSION[1] CONDITIONS EXISTED AT DUNN CENTER SITE FROM SEPTEMBER, 1975 THROUGH AUGUST, 1976

Month	% Frequency of Occurrence	Month	% Frequency of Occurrence
January, 1976	48.5	July	35.6
February	32.5	August	34.0
March	31.2	September, 1975	35.7
April	30.3	October	36.0
May	33.9	November	45.0
June	28.0	December	46.4
	January-December 36.6		

[1] DT/DZ (10m - 100m) $\geqq 1^{o}C/100m$

inversion conditions by hour of day for the one year period is graphed in Figure 19.

Inversions noted from Dunn Center temperature profile data occurred 36.6% of the time during the one-year data collection period. The highest monthly inversion frequency of 48.5% was recorded in January and the lowest in June, 28.0%. Tower profile data are not adequate in describing the existence of inversions aloft or of fumigation potential conditions due to the limitations in the exposure level of the topmost sensor.

Figure 19 indicates that near-surface based inversion occurred nearly 60% of the time during darkness hours. This frequency compares favorably with the 64.3% annual frequency of surface-based inversions recorded in five years of Bismarck data taken at 6:00 a.m. CST from rawinsonde soundings. The inversion frequency from Dunn Center at

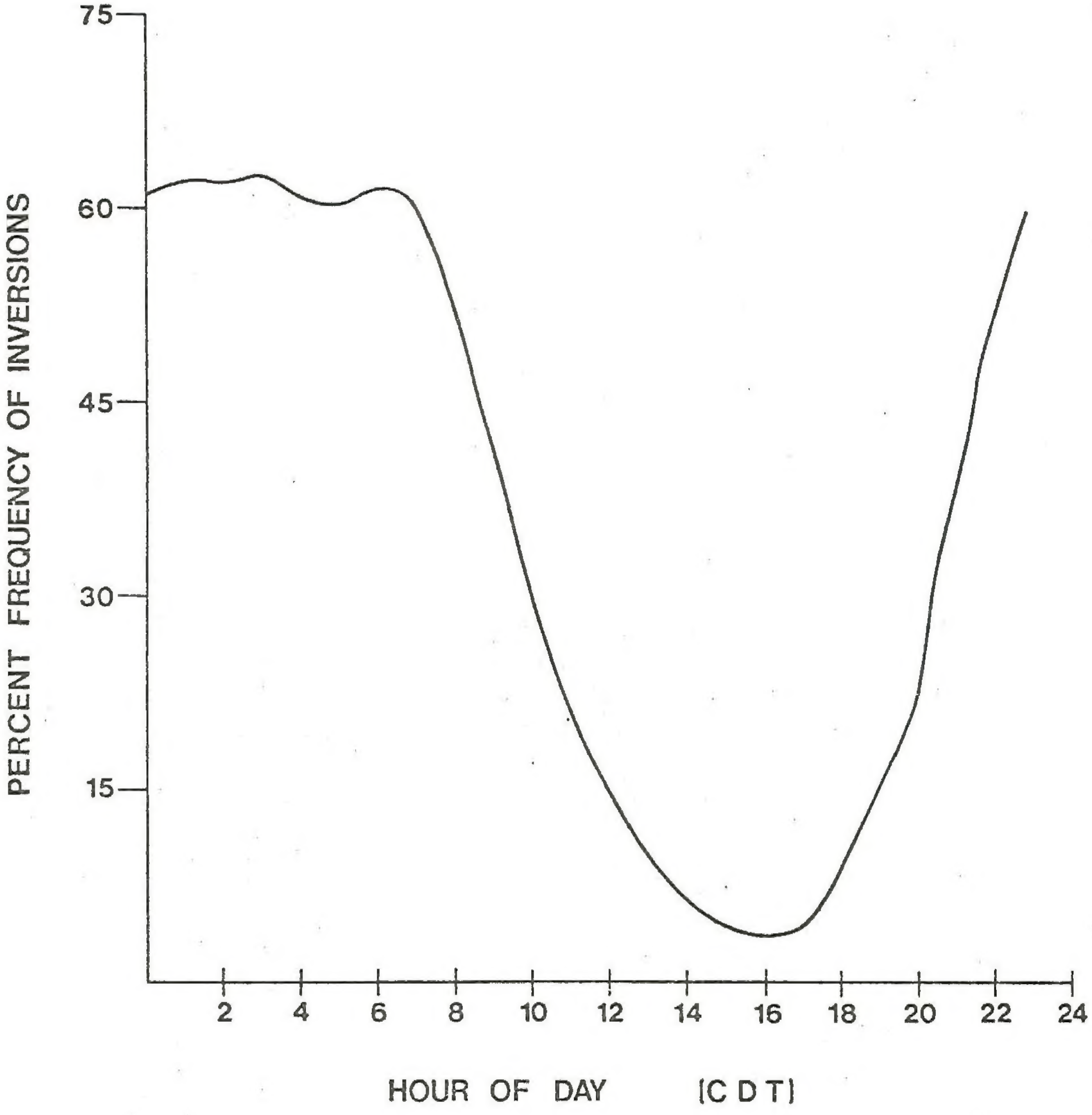


Figure 19. Percent Frequency of Inversion Occurrences by Hour of the Day at Dunn Center from September, 1975 Through August, 1976

6:00 CDT of about 9% is almost identical to the 10.2% frequency found from Bismarck rawinsonde soundings at the same hour. The small percentage of inversions that were found in the afternoon hours at Dunn Center occurred in the winter months. These inversions are most likely nighttime radiation inversions which fail to burn-off because of the high reflectivity of surface snow cover to solar radiation.

The effect of surface-based inversions on wind speed can be noted from the Dunn Center tower data for 10m and 100m. The one-year average of the wind speed at 10m during inversion conditions was 8.6 mph compared to 18.9 mph at 100m. This increase of 10.3 mph from 10m to 100m is significantly greater than the 6.3 mph increase previously mentioned between the two heights for all conditions.

Mixing Layer Heights

Mixing-layer height is defined as the thickness of that atmospheric layer near the earth's surface within which vertical mixing is enhanced relative to the higher air layers. It is determined from the measurement of vertical profiles of air temperatures. From this definition lower values of mixing heights may be interpreted as relatively more severe conditions for air pollution dispersion.

Holzworth's estimates (1972) of mean morning and afternoon mixing heights in the general area of western North Dakota, including the seven county area, are outlined in Table 24.

TABLE 24 MEAN MIXING HEIGHTS (METERS) IN WESTERN NORTH DAKOTA

	Annual	Winter	Spring	Summer	Fall
Morning					
Western N.D.	300-400	300-400	400-500	300	300
Range of U.S. Values	300-900	200-900	300-1000	200-1300	200-1000
Afternoon					
Western N.D.	1500-1600	600-1000	2000-4000	2000-3000	1400-2000
Range of U.S. Values	800-2600	600-1400	800-3400	600-4000	800-2200

Mean mixing-layer heights are generally less thick in the mornings than in the afternoons. Seasonal variations indicate greater afternoon mixing heights during spring and summer than during the other seasons of the year.

AIR POLLUTION EPISODES

Holzworth calculated the averages of observed wind speed within the estimated mixing layers. Higher wind speeds tend to enhance the transport and dilution of atmospheric contaminants within the mixing depth. Afternoon wind speeds of 6 to 9 miles per hour are generally greater than the corresponding morning values.

Shallow mixing depths combined with low wind speeds will tend to inhibit dispersion of air contaminants. Such conditions of restricted dispersion have also been investigated by Holzworth according to their varying degrees of severity. Episodes of at least two days in length of various combination of mixing heights and wind speeds were summarized for the 1960-1964 period. Results of this evaluation for Bismarck, North Dakota are summarized in Table 25. The greatest frequency of air pollution episodes are observed in winter.

TABLE 25 NUMBER OF AIR POLLUTION EPISODES LASTING TWO OR MORE DAYS IN FIVE YEARS AND TOTAL EPISODE DAYS (IN PARENTHESIS) IN BISMARCK, NORTH DAKOTA

Wind Speed	Mixing Heights			
	500 m	1000m	1500m	2000m
≤ 2.0 m/sec	0(0)	0(0)	0(0)	0(0)
≤ 4.0 m/sec	5(12)	6(15)	8(19)	9(21)
≤ 6.0 m/sec	12(30)	20(56)	29(77)	38(99)

CHAPTER III
DESCRIPTION OF WIND AND ATMOSPHERIC STABILITY FOR ATTACHED INPUT DATA ON ATMOSPHERIC DISPERSION MODELING

This final report includes as attachments and enclosures, several materials which have been processed for direct computer inputs to atmospheric dispersion models which are currently operational at the North Dakota State Health Department (NDSHD) Division of Environmental Engineering. Computer printouts of pertinent meteorological data which were analyzed to assist the NDSHD in determining short and long term dispersion model input meteorological conditions are also submitted as parts of this report. These materials are formatted for use in the UNAMAP's Climatological Dispersion Model (CDM) and the three short-term models: PTMAX, PTMTP and PTDIS.

Wind Roses by Stability Class

The CDM uses a wind speed/wind direction relative frequency distribution by stability class to determine long-term ground-level pollutant concentration estimates from one or more pollutant sources. The stability class wind roses used in the long-term climatological model give the relative frequency of occurrence of a stability class for several wind speed intervals at each of 16 wind directions. An example of complete wind speed/wind direction relative frequency distributions by stability class for Bismarck, 1948-1974, and Dunn Center, September 1975 through August, 1976, were given in Chapter II.

The National Climatic Center (NCC) through its STAR program, computed stability class wind roses from surface hourly observation data for all first-order NWS stations based on eight observations per day between 1960 and 1964. The determination of stability class was based on the Pasquill-Turner classification scheme described in Chapter II. This procedure and the method used by the NCC in their STAR program for computing wind distribution by Pasquill stability classes is explained in Appendix I.

Since the STAR program data is only based on eight observations per day over a five-year period, stability class wind roses were calculated for the entire period of record from the NWS hourly observation data in Bismarck (1948-1974), Dickinson (1948-1964), Minot (1948-1974), and Williston (1950-1974). These wind distributions were based on 24 hourly observations per day through 1964 and eight observations per day after 1964, when the NCC discontinued storage of all 24 observations taken on each day. For comparison, separate stability class wind roses were computed for the periods 1948-1964 and 1948-1974.

The computational method used by NDSU was identical to the STAR program method explained in Appendix I except for a few differences. In the NDSU procedure, the number of calms for a particular stability were distributed proportionate to the frequency of observations in the 1-3 knot speed category of each wind direction, instead of both the 1-3 and 4-6 knot categories used by the STAR program. In addition, the NDSU computational method in the insolation class number was assigned as a function of month and time of day to reduce computer time required if it depended on the day of the year and time of day. Errors of 1° to 2° in the solar altitude may result but, as can be seen in Table A-2 of Appendix I, these errors are negligible.

The CDM uses a data deck consisting of 96 computer cards containing the frequency of occurrence of wind speed categories for all 16 wind directions for each of the 6 Pasquill stability classes. The following CDM long-term data decks are submitted to NDSHD as Attachment 1 (computer listing plus 4 boxes of cards) to this report.

Bismarck	1948-1974	12 monthly	1 annual
Dickinson	1948-1964	12 monthly	1 annual
Minot	1948-1974	12 monthly	1 annual
Williston	1948-1974	12 monthly	1 annual

These materials consist of 55 data decks or 5280 keypunched cards. The corresponding computer printouts of the above stability class wind roses are also submitted as Attachment 2 to this report. The printouts include monthly and annual wind roses for the period of record as described in Chapter II.

The stability class wind rose data described above are averages over the period of record and consequently underestimate the worst case average ground-level pollutant concentrations using the CDM. To provide guidelines in modeling for worst case conditions, yearly stability class wind roses were computed for Bismarck for each year between 1948 and 1974. These 27 one-year WS/WD-by-SC analyses are also included as Attachment 3 (listing plus two boxes of cards) to this report. The computer printout with these contains both monthly and annual stability class wind roses for all years. The computer program used to process these data may easily be modified to produce outputs in punched cards or printouts of the stability class wind roses for any year on record and for any of the four NWS stations. Specific input decks for CDM modeling for any year or any of the four stations are available from NDSU upon request.

The relative frequency distributions of wind speed/wind direction by stability class were also determined from wind and temperature profile data collected near Dunn Center from September, 1975 through August, 1976. Stability class wind rose data decks for use in CDM which were calculated from both 10m and 100m data for each month and for a one-year average are also submitted with this report (Attachment 4, two boxes of cards). Though covering a much shorter period of time than the NCC surface data, the tower wind and temperature profile stability data are considered more representative of the atmospheric dispersion conditions in the boundary layer than what can be estimated from surface data.

Short-Term Modeling

The EPA's UNAMAP short-term dispersion models, PTMTP and PTDIS, use meteorological data input cards containing hourly average wind speed, wind direction, stability class, mixing height, air temperature and pressure to estimate hourly average pollutant ground-level concentration. Frequently, worst-case meteorological conditions are assumed; that is, conditions which are known to exist in the area of concern which will cause the highest pollutant ground-level concentrations are chosen and modeled. For many applications, real-time meteorological conditions expected to occur in the area of concern are used as input into existing dispersion models. The NCC hourly observations and Dunn Center data were analyzed to provide meteorological data input information for both worst-case and real-time dispersion modeling.

For real-time modeling using PTMTP and PTDIS, meteorological data input cards with data and format compatible to the batch version of these UNAMAP programs were prepared from NCC hourly surface observation data from Bismarck for January, April, July and October, 1964. Meteorological conditions representative of all four seasons and all times of the day are thus made available for use in dispersion modeling. A total of 2952 computer cards are included with the computer listing of the results of this processing (Attachment 5, listing plus two boxes of cards). The computer program used to abstract these cards from the raw NCC magnetic tape data is available. This program can be readily modified to punch out data cards for any period of time and for any of the four NWS stations for use with PTMTP or PTDIS modeling. Additional data cards for any station and period are available upon request. Unlimited mixing was assumed for all unstable and neutral stabilities and the mixing height was accordingly set equal to 3000m for these cases. The concept of a mixing height is not used for stable conditions. It must be reiterated that the meteorological data punched from NCC data represents conditions at the surface and are not averages through the depth of the dispersion layer.

The NCC surface data and Dunn Center tower data were also analyzed in order to assist in choosing worst-case meteorological conditions for short-term dispersion modeling. In addition to the stability class wind rose and stability class frequency data available from the computer printouts previously described, the NCC hourly observation data was analyzed to determine the frequency of stability class by hour of the day and the persistence of stability class for several duration intervals. These climatological parameters are discussed in Chapter II. Computer printouts of these analysis programs are submitted with this report (Attachment 6). These materials include the monthly and annual frequencies of stability class for each hour of the day for the entire period of record from NCC surface hourly observation data at Bismarck, Dickinson, Minot and Williston, and one-year of tower data from Dunn Center. Similarly, the persistence-of-stability-class-analysis results are also included. The latter however, covers only the period up to and through 1964, since persistence studies require availability of consecutive hourly observations (24 observations a day). Computer printouts of data from the Dunn Center tower site are available upon request.

APPENDIX I

MONTHLY AND ANNUAL

JOB NO. 14627

WIND DISTRIBUTION BY PASQUILL STABILITY CLASSES (STAR PROGRAM) (6 Classes)

STATION: #24012, Dickinson, N. D. PERIOD: Jan. 1960-Dec. 1964 (8 Obs/Day)

Data are presented by stability classes and also combined for the period indicated; first, as a bivariate frequency distribution of wind direction vs. wind speed, and second, as normalized values (i.e., relative frequency). Stability classes used are based on Pasquill's class structure (see Journal of Applied Meteorology, February 1964), as follows:

Pasquill Stability Class	Identified in lower left corner in this tabulation as:	Definition
1	A	Extremely Unstable
2	B	Unstable
3	C	Slightly Unstable
4	D	Neutral
5	E	Slightly Stable
6-7	F	Stable to Extremely Stable

Average wind speed in knots, to tenths, for each direction and each speed class. Overall average wind speed is computed by

$$\frac{\text{Sum of wind speed}}{\text{Number of occurrences}}$$

NUMBER OF OCCURRENCES: Number of DIR/SPD observations, plus number of calms (winds are tabulated to 16 points; speeds are in knots.)

RELATIVE FREQUENCY OF OCCURRENCES: $\frac{\text{Number of occurrences/stability class}}{\text{Total number of observations}}$

TOTAL NUMBER OF OBSERVATIONS: Number of observations in each, month, season, annual or period.

TOTAL RELATIVE FREQUENCY OF OBSERVATIONS: $\frac{\text{Total number of observations}}{\text{Total number of observations}} = 1.00000$

This normalized (relative frequency) table is self explanatory, except that the calm values have been distributed in the 0-3 speed category based on the number of observations in speed categories 1-3 and 4-6.

Example: Total Obs (N) = 3601 (DJF) $\frac{\text{Number of calms in "C" class (2)}}{\text{N (3601)}} = .0005554$ $\frac{.0005554}{\text{(30) Number obs. in classes 1-3 and 4-6}} = .0000185$

From the South direction there are seven observations in the first two speed categories, hence 7(.0000185) = .0001295
In the first category there are 2 observations. 2/3601=.0005554 When added together .0005554 + .0001295=.0006849 the resultant (.000685)
figure is placed in the South 0-3 category and .001389 in the South 4-6 category. This method is used to distribute the calms into the 0-3
speed category, by directions.

JOB NO.

A STABILITY CLASSIFICATION BASED ON HOURLY AIRPORT OBSERVATIONS

The following explanation of the Pasquill Stability classification has been extracted from an article by D. Bruce Turner in the February 1964 Journal of Applied Meteorology.

This system of classifying stability on an hourly basis for research in air pollution is based upon work accomplished by Dr. F. Pasquill of the British Meteorological Office (1961). Stability near the ground is dependent primarily upon net radiation and wind speed. Without the influence of clouds, insolation (incoming radiation) during the day is dependent upon solar altitude, which is a function of time of day and time of year. When clouds exist their cover and thickness decrease incoming and outgoing radiation. In this system insolation is estimated by solar altitude and modified for existing conditions of total cloud cover and cloud ceiling height. At night estimates of outgoing radiation are made by considering cloud cover. This stability classification system has been made completely objective so that an electronic computer can be used to compute stability classes. The stability classes are as follows: 1) Extremely unstable, 2) Unstable, 3) Slightly unstable, 4) Neutral, 5) Slightly stable, 6) Stable, 7) Extremely stable. Table A-1 gives the stability class as a function of wind speed and net radiation. The net radiation index ranges from 4, highest positive net radiation (directed toward the ground), to -2, highest negative net radiation (directed away from the earth). Instability occurs with high positive net radiation and low wind speed, stability with high negative net radiation and light winds, and neutral conditions with cloudy skies or high wind speeds.

The net radiation index used with wind speed to obtain stability class is determined by the following procedure:

1) If the total cloud cover is 10/10 and the ceiling is less than 7000 feet, use net radiation index equal to 0 (whether day or night).

2) For night-time (night is defined as the period from one hour before sunset to one hour after sunrise):
   a) If total cloud cover ≤ 4/10, use net radiation index equal to -2.
   b) If total cloud cover > 4/10, use net radiation index equal to -1.

3) For daytime:
   a) Determine the insolation class number as a function of solar altitude from Table A-2.
   b) If total cloud cover ≤ 5/10, use the net radiation index in Table A-1 corresponding to the insolation class number.
   c) If cloud cover > 5/10, modify the insolation class number by following these six steps:
      1) Ceiling < 7000 ft, subtract 2.
      2) Ceiling ≥ 7000 ft but < 16,000 ft, subtract 1.
      3) Total cloud cover equal 10/10, subtract 1. (This will only apply to ceilings ≥ 7000 ft since cases with 10/10 coverage below 7000 ft are considered in item 1 above.)
      4) If insolation class number has not been modified by steps (1), (2), or (3) above, assume modified class number equal to insolation class number.
      5) If modified insolation class number is less than 1, let it equal 1.
      6) Use the net radiation index in Table A-1 corresponding to the modified insolation class number.

Since urban areas do not become as stable in the lower layers as non-urban areas, stability classes 5, 6 and 7 computed using the STAR program may be combined into a single class (5), or classes 6 and 7 may be combined and identified as class 6.

A STABILITY CLASSIFICATION BASED ON HOURLY AIRPORT OBSERVATIONS (CONT'D) (STAR PROGRAM)

TABLE A-1. STABILITY CLASS AS A FUNCTION OF NET RADIATION AND WIND SPEED

WIND SPEED (KNOTS)	NET RADIATION INDEX						
	4	3	2	1	0	-1	-2
0, 1	1	1	2	3	4	6	7
2, 3	1	2	2	3	4	6	7
4, 5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8, 9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
$\geq$12	3	4	4	4	4	4	4

TABLE A-2. INSOLATION AS A FUNCTION OF SOLAR ALTITUDE

SOLAR ALTITUDE (α)	INSOLATION	INSOLATION CLASS NUMBER
$60° < \alpha$	Strong	4
$35° < \alpha \leq 60°$	Moderate	3
$15° < \alpha \leq 35°$	Slight	2
$\alpha \leq 15°$	Weak	1

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AN AIR QUALITY ASSESSMENT OF PROPOSED ENERGY DEVELOPMENTS IN A SEVEN COUNTY AREA OF WESTERN NORTH DAKOTA

AN AIR QUALITY ASSESSMENT OF PROPOSED ENERGY DEVELOPMENTS IN A SEVEN COUNTY AREA OF WESTERN NORTH DAKOTA

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ABSTRACT

The air quality assessment of proposed energy development in western North Dakota described in this document was initiated in early 1975. It resulted from a memorandum of understanding between the Governor of North Dakota and the Regional Director of the Bureau of Land Management, U.S. Department of the Interior, for the purpose of cooperation in planning and in environmental concerns as they relate to future energy development in western North Dakota. Subsequent to the memorandum, the Governor and the Secretary of the Interior adopted a plan for a joint Federal-State Environmental Impact Study on Energy Development in west central North Dakota. This document constitutes the technical data and information which served as the basis for the Climate and Air Quality sections of the joint Federal-State Impact Study.

The proposed energy developments subject to evaluation were set forth by the Bureau of Land Management in three phases of development spanning a time period from the late 1970's through 1990. The phases were subsequently identified into three levels of proposed development. Level 1 developments were those active energy-related projects currently in some stage of review and consideration by various regulatory agencies of government. Level 2 developments were those which have been identified by industry as being tentative future developments. Level 3

proposals were identified as potential coal reserve utilization of areas after 1990.

The Air Quality assessment was performed in accordance with the guidelines established for the three proposed levels of development. Within the scope of this analysis, technical data and information were developed to serve as guidelines and tools in the air quality portions of the Environmental Impact Study. The key areas presented within the scope of this document include ambient air quality rules and regulations, ambient air contaminant sources, baseline information on the existing environment, and projections of potential changes of the existing air quality with the various levels of proposed development.

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AMBIENT AIR QUALITY RULES AND REGULATIONS

Background

With the passage of the 1970 amendments to the Federal Clean Air Act, the states were directed to establish, implement, and enforce air quality regulations under the supervision of the United States Environmental Protection Agency (EPA). As an aid for developing the State Implementation Plan, a classification system was established by EPA to categorize air quality control regions as presented in Table 1. The classification is based upon measured ambient air quality, where known, or estimated contaminant concentrations in the areas where no air quality data existed. Each region has been classified separately with respect to each of the following five contaminants: sulfur oxides, particulate matter, carbon monoxide, nitrogen dioxide, and photochemical oxidants as presented in Table 2. The air quality control region (No. 172) within which the study region lies, is classified Priority II for particulate matter and Priority III for the remaining four contaminants.

Ambient Air Quality Standards

The EPA, under the Clean Air Act of 1970, is required to establish national ambient air quality standards for air contaminants. National primary standards to protect health and secondary standards to protect public welfare have been promulgated for six contaminants. The six contaminants are sulfur oxides, particulate matter, carbon monoxide,

TABLE 1

CLASSIFICATION OF AIR QUALITY CONTROL REGIONS IN NORTH DAKOTA

Air Quality Control Region	Regional Classification1/					Basis for Classification2,3/				
	Particulate	SO_x	CO	NO_2	Photo-chemical Oxidants	Particulate	SO_x	CO	NO_2	Photo-chemical Oxidants
Region No. 130, Metropolitan Fargo-Moorhead Interstate Air Quality Control Region (North Dakota-Minnesota)	II	III	III	III	III	A	A,B,C	E	E	E
Region No. 172, North Dakota Intrastate Air Quality Control Region	II	III	III	III	III	A	A,B,C	E	E	E

SOURCE: State Implementation Plan for the Control of Air Pollution for the State of North Dakota, North Dakota State Department of Health, January 24, 1972.

1/ Regional Classification Codes:

Code	Definition
I	Priority I Region
Ia	Priority Ia Region
II	Priority II Region
III	Priority III Region

2/ Basis for Classification Code:

Code	Basis
A	Measured Air Quality Data
B	Estimated Air Quality Miller-Holzworth Area Model
C	Estimated Air Quality Point Source Model
D	Urban Place Population ≥200,000
E	Urban Place Population <200,000

3/ Measured Air Quality Data and Estimated Air Quality from Area and Point Source Models are presented in Section 3. Control Strategy.

TABLE 2

FEDERAL PRIORITY CLASSIFICATIONS BASED ON AMBIENT (OR ESTIMATED) AIR QUALITY

		PRIORITY		
Pollutant	Averaging Time	I Greater Than	II From - To	III Less Than
Sulfur Oxides	Annual Average	100 $\mu g/m^3$ (0.04 ppm)	60-100 $\mu g/m^3$ (0.02-0.04 ppm)	60 $\mu g/m^3$ (0.02 ppm)
	24-Hour Maximum	455 $\mu g/m^3$ (0.17 ppm)	260-455 $\mu g/m^3$ (0.10-0.17 ppm)	260 $\mu g/m^3$ (0.10 ppm)
	3-Hour Maximum	--- ---	Above 1300 $\mu g/m^3$ (0.50 ppm)	1300 $\mu g/m^3$ (0.50 ppm)
Particulate Matter	Annual Average	95 $\mu g/m^3$	60-95 $\mu g/m^3$	60 $\mu g/m^3$
	24-Hour Maximum	325 $\mu g/m^3$	150-325 $\mu g/m^3$	150 $\mu g/m^3$
Nitrogen Dioxide	Annual Average	110 $\mu g/m^3$ (0.06 ppm)	NC[1]	110 $\mu g/m^3$ (0.06 ppm)
Carbon Monoxide	8-Hour Maximum	14 mg/m^3 (12 ppm)	NC	14 mg/m^3 (12 ppm)
	1-Hour Maximum	55 mg/m^3 (48 ppm)	NC	55 mg/m^3 (48 ppm)
Photochemical[2] Oxidants	1-Hour Maximum	195 $\mu g/m^3$ (0.10 ppm)	NC	195 $\mu g/m^3$ (0.10 ppm)

Source: Paragraph 51.3, page 31, CFR July 1, 1976.

NOTE: In absence of measured data or estimated data to the contrary, any region containing an area whose 1970 "urban place" population exceeds 200,000 will be classified Priority I. All other regions will be classified Priority III.

[1] NC = No Priority II classification.

[2] Classifications with respect to hydrocarbons will be the same as the classification with respect to photochemical oxidants.

photochemical oxidants, hydrocarbons, and nitrogen oxides (See Table 3).

Sulfur oxides originate primarily from the combustion of sulfur containing fossil fuels. Their presence has been associated with the increased incidents of respiratory diseases, increased deaths and property damage.

Particulate matter, either solid or liquid, may originate in nature or as a result of industrial processes and other human activities. By itself or in association with other contaminants, particulate matter may injure the lungs or cause adverse effects elsewhere in the body. Particulates also reduce visibility and contribute to property damage and soiling.

Carbon monoxide is a byproduct of the incomplete burning of carbon-containing fuels and of some industrial processes. It decreases the oxygen-carrying ability of the blood and, at levels often found in urban air may impair mental processes. Both the one-hour and the eight-hour standards afford protection against the occurrence of carboxy-hemoglobin levels in the blood. Carboxy-hemoglobin levels above 5 percent have been associated with physiological stress in patients with heart disease. Blood carboxy-hemoglobin levels approaching 2 percent have been associated by some researchers with impaired physchomotor responses.

TABLE 3

FEDERAL PRIMARY AND SECONDARY AIR QUALITY STANDARDS

Air Contaminant	Averaging Time	Federal Primary Standard	Federal Secondary Standard
Nitrogen Dioxide[1]	Annual Average	100 μg/m^3 (0.05 ppm)	100 μg/m^3 (0.05 ppm)
Sulfur Dioxide	Annual Average	80 μg/m^3 (0.03 ppm)	---
	24-Hour	365 μg/m^3 (0.14 ppm)	---
	3-Hour	---	1300 μg/m^3 (0.5 ppm)
Suspended Particulate	Annual Geometric Mean	75 μg/m^3	60 μg/m^3
	24-Hour	260 μg/m^3	150 μg/m^3
Hydrocarbons (corrected for Methane)	3-Hour 6-9 A.M.	160 μg/m^3 (0.24 ppm)[2]	160 μg/m^3 (0.24 ppm)
Photochemical Oxidants	1-Hour	160 μg/m^3 (0.08 ppm)	160 μg/m^3 (0.08 ppm)
Carbon Monoxide	8-Hour	10 mg/m^3 (9 ppm)	10 mg/m^3 (9 ppm)
	1-Hour	40 mg/m^3 (35 ppm)	40 mg/m^3 (35 ppm)

SOURCE: 38 Code of Federal Regulations 25678, September 14, 1973

NOTE: ppm = parts per million
μg/m^3 = micrograms per cubic meter
mg/m^3 = milligrams per cubic meter

[1] Nitrogen dioxide is the only one of the nitrogen oxides considered in the ambient standards.

[2] Maximum 3-hour concentration between 6-9 A.M.

Photochemical oxidants are produced in the atmosphere when reactive organic substances, chiefly hydrocarbons and nitrogen oxides, are exposed to sunlight. Photochemical oxidants irritate mucous membranes, reduce resistance to respiratory infection, damage plants, and contribute to the deterioration of materials (Perkins 1974).

Hydrocarbons in the air come mainly from the processing, storage marketing and use of petroleum products. Some of the hydrocarbons combine with nitrogen oxides in the air to form photochemical oxidants. The hydrocarbon standards, therefore, are for use as a guide in devising implementation plans to achieve the oxidant standards.

Nitrogen oxides usually originate in high-temperature combustion processes. The presence of nitrogen dioxide in the air has been associated with a variety of respiratory diseases. Nitrogen dioxide is essential in the natural production of photochemical oxidant (Perkins 1974).

The states may adopt and promulgate their own ambient air quality standards as long as they are equal to or more stringent than the Federal Ambient Air Quality Standards promulgated by the EPA. The North Dakota State Department of Health has promulgated Ambient Air Quality Standards for the State of North Dakota. The State Standards are equal to or more stringent than the Federal Secondary Standards for the six Federal contaminants. The State has also adopted standards for settled particulates, coefficient of haze, reactive sulfur, suspended sulfates, sulfuric acid mist and sulfur trioxide, and hydrogen sulfide.

The purpose of the State Ambient Air Quality Standards is that the quality of the air in North Dakota should be such that (a) the health of sensitive or susceptible segments of the population will not be adversely affected; (b) concentrations of pollutants will not cause public nuisance or annoyances; (c) significant damage to animals, ornamental plants, forest and agricultural crops will not occur; (d) visibility will not be significantly reduced; (e) metals or other materials will not be significantly corroded or damaged; (f) fabrics will not be soiled, deteriorated or their colors affected; and (g) natural scenery will not be obscured. The North Dakota Ambient Air Quality Standards are presented in Table 4.

Prevention of Significant Deterioration of Air Quality Regulations

The EPA in response to the May 30, 1972 court decision, (Sierra Club versus Ruckelshaus) affirmed in 1973 by the Supreme Court, promulgated regulations on December 5, 1974, to Prevent the Significant Deterioration (PSD) of air quality. The EPA PSD Regulations are effective nationwide. This is because the EPA disapproved all state implementation plans that did not contain adequate procedures for preventing significant deterioration in

TABLE 4

STATE OF NORTH DAKOTA AIR QUALITY STANDARDS

Air Contaminant (Units)	Averaging Time	Maximum Permissible Concentration
Total Suspended Particulates (μg/m^3)[1]	Annual Geometric Mean	60
	24-hour	150[2]
Settled Particulate - Dustfall (tons per square mile per month)	3-month	15[3]
	3-month	30[4]
Coefficient of Haze (Coefficient of Haze per 1,000 linear feet)	Annual Geometric Mean	0.4
Sulfur Dioxide (μg/m^3)	Annual Average	60
	24-hour	260
	1-hour	715
Reactive Sulfur (mg/100cm^2/day)[5]	Annual Average	0.25
	1-month	0.50
Suspended Sulfates (μg/m^3)	Annual Average	4
	24-hour	12[6]
Sulfuric Acid Mist, Sulfur Trioxide or Combination (μg/m^3)	Annual Average	4
	24-hour	12[6]
	1-hour	30[6]
Hydrogen Sulfide (μg/m^3)	1/2-hour	45[7]
	1/2-hour	75[8]
Carbon Monoxide (mg/m^3)[9]	8-hour	10[2]
	1-hour	40[2]
Photochemical Oxidants (μg/m^3)	1-hour	160[2]
Hydrocarbons (μg/m^3)	3-hour (6-9 a.m.)	160[2]
Nitrogen Dioxide (μg/m^3)	Annual Average	100
	1-hour	200[10]

SOURCE: North Dakota State Department of Health Air Pollution Control Regulations, 1976 any portion of any state where the air is cleaner than the National Ambient Air Quality Standards.

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[1] μg/m^3 is the abbreviation for micrograms per cubic meter.
[2] Maximum not to be exceeded more than once per year.
[3] Maximum in a residential area.
[4] Maximum in an industrial area.
[5] mg/100cm^2/day is the abbreviation for milligram sulfur trioxide per 100 square centimeters per day.
[6] Maximum not to be exceeded over 1% of the time.
[7] Maximum not to be exceeded more than twice in any five consecutive days.
[8] Maximum not to be exceeded over twice a year.
[9] mg/m^3 is the abbreviation for milligrams per cubic meter.
[10] Maximum not to be exceeded over 1% of the time in any 3-month period.

The program to prevent significant deterioration of air quality is based on the principle that clean air is a natural resource of great importance. The resource's value cannot always be measured in terms of proven health and property damage. The regulations are the result of a long and detailed study and of extensive public participation, including nationwide public hearings.

At the core of the regulations is the question of what constitutes significant deterioration of clean air and the process and procedures to be used to resolve that question for any given area. Because PSD deals with air quality levels that have not been proven to cause health or property damage, the determination of significant deterioration must take into account factors other than air quality alone. Economic and social effects and subjective concerns such as aesthetic values must also be considered in resolving the question of significance. Because these effects are best evaluated by those who reside in the areas involved, EPA has developed a regulatory framework that gives states, Federal land managers and Indian governing bodies the flexibility to decide what levels of deterioration are significant. Three different levels of allowable incremental increases in total suspended particulate matter (TSP) and sulfur dioxide (SO_2) are set forth for classifying areas. They are summarized in Table 5.

TABLE 5

ALLOWABLE INCREMENTAL INCREASES FOR THE THREE CLASSES OF THE FEDERAL SIGNIFICANT DETERIORATION OF AIR QUALITY STANDARDS

	Class I ($\mu g/m^3$)1/	Class II ($\mu g/m^3$)	Class III ($\mu g/m^3$)
Particulate Matter:			
Annual Geometric Mean	5	10	60
24-Hour Maximum	10	30	150
Sulfur Dioxide:			
Annual Arithmetic Mean	2	15	80
24-Hour Maximum	5	100	365
3-Hour Maximum	25	700	1300

SOURCE: 40 Code of Federal Regulations 52.21, January 1, 1975

1/ micrograms per cubic meter of air ($\mu g/m^3$)

Areas designated Class I or Class II are limited to increases in pollutant concentrations occurring since January 1, 1975. Areas designated as Class III are limited to concentrations no greater than the National Ambient Air Quality Standards, which are the values listed under Class III in Table 5.

The three classifications reflect the desired degree of change from the current levels of air quality. In areas designated Class I, practically any degradation in air quality would be considered significant and very limited growth or development could occur. In areas designated Class II, deterioration normally accompanying well-controlled moderate growth would be considered insignificant and limited growth and development could occur. In areas designated Class III, deterioration up to the National Ambient Air Quality Standards would be considered insignificant and large scale growth and development could occur.

The PSD regulation is implemented through a preconstructon review program (permit to construct) of specified source categories to determine if a violation of the appropriate increment might occur. The source categories are required to use best available control technology. This stipulation applies to the designated source categories wherever they are located.

EPA has the responsibility for preconstruction review throughout the nation. EPA can, however, delegate this responsibility to a state provided it has adequate preconstruction review procedures and has promulgated its own PSD regulations. The State Department of Health has promulgated PSD Regulations for the State of North Dakota to qualify for this delegation. The North Dakota Prevention of Significant Deterioration of Air Quality Regulations went into effect February 9, 1976. The EPA withdraw the Federal regulations from the State of North Dakota and delegated responsibility for prevention of significant deterioration to the State Health Department May 26, 1977.

The State of North Dakota regulations are very similar to the Federal regulations. The State regulation has the same air quality increment system as the EPA regulations. The major difference between the State regulation and the Federal is that it requires industry to consider pollution from associated growth in using up the increment as well as by emissions from the facility itself.

Redesignation of any area may be proposed by the State, Federal land managers, or Indian reservation governing bodies. Federal land managers are restricted to redesignation from Class II to Class I only. States and Indian governing bodies can reclassify from Class II to either Class I or Class III. The State, however, cannot reclassify Indian lands. This is a function of the Environmental Protection Agency only.

The effect of the prevention of significant deterioration regulations on air quality in North Dakota where existing levels of sulfur dioxide and total suspended particulate matter are well below the Federal and State Ambient Air Quality Standards will be to put a ceiling on the future increases of these contaminants. This ceiling is well below the State and Federal Ambient Air Quality Standards.

PSD was one of the major issues addressed in the Clean Air Act Amendments of 1977, as signed into law August 7, 1977 by President Carter. The legislation established a detailed system of area classifications and air quality increments designed to prevent significant deterioration of air quality in clean-air areas, those in which major contaminants were monitored at levels below those established by the National Ambient Air Quality Standards.

According to the 1977 Amendments, certain PSD provisions were effective immediately, with others delayed until such time as State Implementation Plans could be revised. New regulations proposed by the U.S. Environmental Protection Agency on November 3, (Federal Register, Volume 42, No. 212) would establish an implementation date of March 1, 1978, for those PSD regulations which were to have been delayed, pending revision of state plans.

Under the PSD regulations in effect prior to enactment of the 1977 Amendments, 19 major stationary source categories were identified as being subject to PSD preconstruction review procedures under the EPA regulations and 21 major stationary source categories under the existing North Dakota regulations. The new Amendments expand these to include 28 major stationary source categories with the potential to emit more than 100 tons per year of any contaminant. Also included are any sources with the potential to emit 250 tons per year of any contaminant.

A more stringent definition of Best Available Control Technology (BACT) will be required for all sources subject to the PSD provisions for any contaminant regulated under the act for which there is a potential emission rate of 100 tons per year. The Amendments include provisions for contaminants other than those for which National Ambient Air Quality Standards have been set (criteria contaminants). BACT will also be required for modifications or expansions of existing sources, if such sources are included among those specified by the legislation as being subject to PSD requirements.

Increments for the maximum allowable increases of particulates and sulfur dioxide are established. An ambient review of the impact of increased emissions from new sources or modified existing sources is required to assure that these emissions will not contribute to a violation of the established increments. Modifications to existing sources which would result in an overall decrease over current emissions would not be subject to this procedure.

PSD review will allow opportunity for a public hearing before a final decision is made by a state regulatory agency on awarding of the permit. Applications for permits after August 7, 1978, by sources subject to PSD review must be accompanied by an analysis of one year of continuously measured air quality data for all criteria contaminants. Monitoring will not be required for nonmethane hydrocarbons and for sources for which the increased potential emissions would not exceed 100 tons per year.

All preconstruction review requirements, as outlined above, would apply to any source which does not obtain a final PSD permit approval before March 1, 1978. The proposed EPA regulations state: "It is imporant to note that EPA's current PSD regulations contemplate at least a 90-day period from completed application submission to permit issuance. Accordingly, sources which have not filed completed applications by December 1, 1977, should not assume that a final permit approval will be issued by March 1, 1978, and should therefore plan to be reviewed under the new rules."

Sources obtaining final permit approval prior to the March 1 deadline, but not commencing construction before December 1, 1978, would also be subject to the PSD review requirements.

Certain areas were automatically classified as Class I, thus subject to the most stringent restraints on air quality deterioration. These areas include all international parks, all national wilderness areas which exceed 5,000 acres in size, all national memorial parks which exceed 5,000 acres in size, and all national parks which exceed 6,000 acres in size. This designation applies only to areas which were in existence on the date of enactment of the new Amendments. These areas may not be redesignated. In North Dakota, these areas include the Lostwood National Wilderness Area (5,577 acres), and the Theodore Roosevelt National Memorial Park (69,675 acres).

The Amendments set forth immediately effective more restrictive ambient air increments for particulate matter and sulfur dioxide in Class I, Class II, and Class III areas (See Table 6). Also immediately effective is the requirement that each National Ambient Air Quality Standard (not just particulate matter and sulfur dioxide) shall act as an overriding ceiling to any otherwise allowable increment. It also provides that for any period other than an annual period, the applicable increment may be exceeded during one such period per year at a given site.

Another immediately effective change involves three provisions concerning the redesignation of areas to Class III. First, certain areas can not be reclassified as a Class III area. These include: (1) an area which exceeds 10,000 acres in size and is a national monument, a national primitive area, a national preserve, a national recreation area, a national wild and scenic river, a national wildlife refuge, a national lakeshore or seashore, and (2) a national park or national wilderness area established after the date of enactment of this Act which exceeds 10,000 acres in size. Second, before any area may be redesignated to Class III, specific approval must be received from the Governor, after consulation with the legislature, and from the local governments representing a majority of the residents in the area which is to be redesignated. Finally, a Class III redesignation must not itself cause or contribute to concentrations of any air

TABLE 6

NEW PREVENTION OF SIGNIFICANT DETERIORATION OF AIR QUALITY INCREMENTS AND CEILINGS CLEAN AIR ACT AMENDMENTS OF 1977

Pollutants	Maximum Allowable Increase[1/] (in micrograms per cubic meter)		
	Class I	Class II	Class III
Particulate Matter			
Annual Geometric Mean	5	19	37
24-hour Maximum	10	37	75
Sulfur Dioxide			
Annual Arithmetic Mean	2	20	40
24-hour Maximum	5	91	182
3-hour Maximum	25	512	700

SOURCE: Clean Air Act Amendments of 1977
Title I, Part C, Section 163
August 7, 1977

[1/] Maximum allowable increases over baseline concentrations not to be exceeded more than once per year.

contaminant which exceed the maximum allowable increase in another area.

The sources subject to PSD review shall continue to be reviewed in both attainment (air quality within NAAQS) and nonattainment (air quality in excess of NAAQS) areas regarding their long-range impact on an increment in any affected area. Also, best available control technology for SO_2 and particulate matter shall still be required at any location. However, PSD sources are not subject to an ambient air review for PSD increments or National Ambient Air Quality Standards (NAAQS) ceilings as regards the nonattainment area itself. In this regard, the "Emission Offset" Interpretative Ruling (40 CFR 55524, December 21, 1976) shall continue to control the construction of sources which cause or contribute to air quality concentrations in excess of any national ambient air quality standard.

The Amendments limit stack height for dispersion of emissions to good engineering practice (GEP), which is defined as that height necessary to avoid atmospheric downwash, wakes and eddies. It indicates that GEP should generally not exceed two and one-half times the height of the source (subject to exemption based on appropriate showing by the source). EPA is required to issue regulations within six months to implement this provision. Until these regulations are issued, the allowable stack height for dispersion of emissions would use the "two and one-half times" rule unless the source can justify a higher stack.

EPA must re-examine any previous PSD approval which was based on a stack height which exceeded GEP (two and one-half times the height of the source), if the source did not commence construction before August 7, 1977. Any subsequent PSD reviews will have to be based on a GEP stack height for the applicant as well as for any sources which have received previous PSD approval. That is, if any increment would have been violated had all sources been limited to GEP stack heights, no additional sources would be allowed to locate in that area.

The North Dakota State Department of Health will be required to revise Regulation R23-25-15, the Prevention of Significant Deterioration of Air Quality, which went into effect on February 9, 1976, and the State Implementation Plan to comply with the requirements of the 1977 Clean Air Act Amendments and EPA's proposed new regulations. It is anticipated these revisions will be adopted by July 1978. In the interim, the Department will follow the Amendments in its PSD new source reviews.

New Source Performance Standards (NSPS)

The Clean Air Act of 1970 building on prior Federal,state and local agency legislation and experience, authorized a national program of air pollution prevention and control which included receptor/effect and specification standards, emission standards for mobile sources, and--for the first time--nationwide uniform emission standards for new and modified stationary sources.

Section 111 of the 1970 Act requires the establishment of Standards of Performance for New Stationary Sources of air contaminants which ". . . may contribute significantly to air pollution which causes or contributes to the endangerment of public health or welfare". These Standards of Performance for New Stationary Sources are commonly referred to as New Source Performance Standards or NSPS.

The major purpose of NSPS is that of preventing new air pollution problems. Section 111 of the 1970 Act, therefore, requires the application of the best, adequately demonstrated, system of emission reduction (taking into account the cost). This provides control of existing sources which increase emissions, and can be applied to both new and existing sources of a contaminant not regulated by Sections 109 (National Ambient Air Quality Standards) and 112 (National Emission Standards for Hazardous Air Contaminants). Standards may apply to specific equipment and processes, or to entire plants and facilities [Section 111(b)(2)], and may be revised whenever necessary. Since the standards are based on emissions, the owner or operator of a source may select any control system desired, but he must achieve the standard.

NSPS may be used to compliment other standards (ambient air quality, hazardous pollutant, or mobile source), or may constitute the sole approach to controlling a specific air contaminant or air contaminant source. The National Ambient Air

Quality Standards (NAAQS) are attained through state implementation plans (SIP) and mobile source emission standards. The SIP are based on emission inventories. NSPS provide the standard test methods and accurate emission measurements required for a meticulous emission inventory. The emission measurements made during NSPS development can be used to support SIP regulations, and usually prove easier to enforce than a general regulation because they are tailored to specific sources. By imposing more stringent control on new sources, NSPS extend the usefulness of SIP's and of control equipment by reducing the rate at which emissions increase.

Protection of air quality is also aided by NSPS. Prevention of Significant Deterioration (non-degradation) Regulations, as a minimum, require that SIP apply best available control technology to specified categories of new sources. Usually, NSPS will represent best technology. For sources not subject to NSPS, selection of best available control technology may be aided by NSPS studies and by transfer of NSPS-determined technology between similar industries.

Hazardous contaminant standards (Section 112) which do not require absolute best control to protect public health can be supplemented by NSPS that (1) minimize environmental accumulation of the contaminant if long-term effects are suspected and (2) increase margins of safety gradually, with less economic impact, by requiring best control of new sources.

Even if the hazardous contaminant standard represents best existing technology, NSPS can be applied as control technology improves, increasing the margin of safety without penalizing existing plants.

Finally, NSPS can be used alone to control emissions of designated contaminants. This is the most feasible approach when emissions of a pollutant could endanger public health or welfare if not limited, but the number of existing sources is small. In situations where neither hazardous nor ambient air standards are justified, NSPS may be used. Public health could, for example, be endangered yet there could be insufficient data to set ambient air standards that would with certainty protect the public. Or a contaminant may affect public welfare, but not public health, another situation where NSPS could be used instead of the more complex SIP approach.

The U.S. Environmental Protection Agency, as of October 31, 1977 has promulgated NSPS for twenty-four categories of new or modified stationary sources. These performance standards specify emission limits for particulates, sulfur dioxide, nitrogen oxides, sulfuric acid mist, carbon monoxide, hydrocarbons, fluorides, and visible emissions as well as standard test methods to determine compliance.

The U.S. Environmental Protection Agency is authorized to delegate enforcement of NSPS to a state. The North Dakota State

Department of Health adopted eighteen of the twenty-four Federal NSPS effective February 9, 1976 and has been delegated authority to enforce them by the EPA effective August 30, 1976. As an example, State and Federal New Source Performance Standards for fossil fuel-fired steam generators are presented in Table 7.

TABLE 7

EMISSION REGULATIONS FOR FOSSIL FUEL-FIRED STEAM GENERATORS

Air Contaminant	Federal Standard
Particulates	
Solid:	0.1 lb/10^6 BTU input[1]
Liquid:	0.1 lb/10^6 BTU input
Gaseous:	0.1 lb/10^6 BTU input
Sulfur Dioxide	
Solid:	1.2 lb/10^6 BTU input
Liquid:	0.8 lb/10^6 BTU input
Gaseous:[2]	
Oxides of Nitrogen	
Solid:[3]	0.7 lb/10^6 BTU input
[4]	0.6 lb/10^6 BTU input
Liquid:	0.3 lb/10^6 BTU input
Gaseous:	0.2 lb/10^6 BTU input

SOURCE: 40 Code of Federal Regulations 60,
Revised July 1, 1976

North Dakota State Department of Health
Air Pollution Control Regulations 1976

1/ Pounds per million British thermal unit heat input (lb/10^6 BTU input)

2/ No existing Federal Standard

3/ Federal Standards exclude lignite coal

4/ Proposed standard for lignite coal

AIR CONTAMINANT SOURCES

The air quality analysis within the scope of this report considered the sources of ambient air contaminants in a seven county area of western North Dakota. This area has been designated by the U.S. Department of the Interior for study and preparation of a west-central North Dakota Regional Environmental Impact Statement involving future energy development. The specific area under study includes the counties of McLean, Mercer, Oliver, Dunn, Stark, Burleigh, and Morton.

The sources of contaminants to the ambient air of the study area include two classifications with respect to contaminant origin. The first classification is that of area-wide sources which includes vehicular traffic, agriculture, construction, and mining activities, and miscellaneous actions involving the consumption of fossil fuels. The remaining classification is composed of point sources and includes specific industrial complexes such as thermoelectric generating facilities, oil refineries, and coal gasification facilities.

The air quality analysis throughout this report considered with both area-wide mining and point sources of contaminants. Table 8 presents a list of existing point and area sources in the study area, their owner, location, number of units and/or the size of each source. Table 8 also includes energy related facilities which have been proposed for construction within the

TABLE 8

EXISTING AND PROPOSED POINT AND MINING RELATED AREA AIR CONTAMINANT SOURCES IN THE STUDY AREA

	Facility Name	Owner	Location	# of Units	Size
.	Heskett Power Plant	Montana-Dakota Utilities (MDU)	Mandan	2	35/55 3/
.	Amoco Oil Reginery	Amoco Oil	Mandan	Multiple	-
.	Milton R. Young Power Plant	Minnkota Power Coop.	Center	2	235/450 3/
.	Baukol-Noonan Coal Mine	Baukol-Noonan Coal Co.	Center	-	1.75 5/
.	Glennharold Coal Mine	Consolidation Coal Co.	Stanton	–	3.47 5/
.	Basin Electric Power Plant	Basin Electric Power Coop.	Stanton	2	210/450 3/
.	United Power Coop	United Power Coop (UPA)	Stanton	1	180 3/
.	Knife River Coal Mine	MDU	Beulah, South	-	1.07 5/
.	Indianhead Coal Mine	North American Coal Co.	Zap	-	1.17 5/
.	MDU Power Plant	MDU	Beulah	1	15 3/
.	Coyote Power Plant 1/	Ottertail Power Coop/MDU	Beulah, South	2	440/440 3/
.	ANG Coal Gasification 1/ Plant	American Natural Gas	Beulah, North	1	250x10⁶ 4/
.	North American Coal Mine 2/	North American Coal Co.	Beulah, North	1	12.2 to 14.7 5/
.	Basin Electric Power 1/ Plant	Basin Electric	Beulah, North	2	450/450 3/
5.	Coal Creek Station	UPA/CPA	Underwood	2	545/545 3/
6.	Falkirk Coal Mine	North American Coal Co.	Underwood	1	5.5 5/
7.	NGPL Coal Gasification 1/ Plant	Natural Gas Pipeline	Dunn Center	1	250x10⁶ 4/
8.	NGPL Coal Mine 2/	NGPL	Dunn Center		
9.	Nokota Coal Mine 2/	Nokota Mining Company	Garrison	-	6.6 5/
0.	Dakota Starr Mine 2/	Consolidation Coal Company	Beulah		4.0 5/
1.	Renners Cove Mine 2/	Consolidation Coal Company	Beulah		3.5 5/
2.	Washburn Coal Mine 2/	Consolidation Coal Company	Washburn		5.0 5/
3	Husky Industries Mine	Husky	Dickinson	1	-
4.	Northland Oil & Refining Co.	Northland	Dickinson	1	-
5.	Underwood Coal Mine 2/	Consolidation Coal Company	Underwood		1.5 5/

SOURCE: North Dakota State Department of Health 1977

1/ Proposed point sources

2/ Proposed Area Sources

3/ Units expressed in megawatts

4/ Units expressed in cubic feet per day

5/ Units expressed in million tons per year boundaries of the seven county study area through the year 1990. The actual air quality analysis has been performed with consideration of all existing sources and the addition of all proposed point and area sources. The locations of the existing and proposed sources as presented in Table 8 are shown in Figure 1.

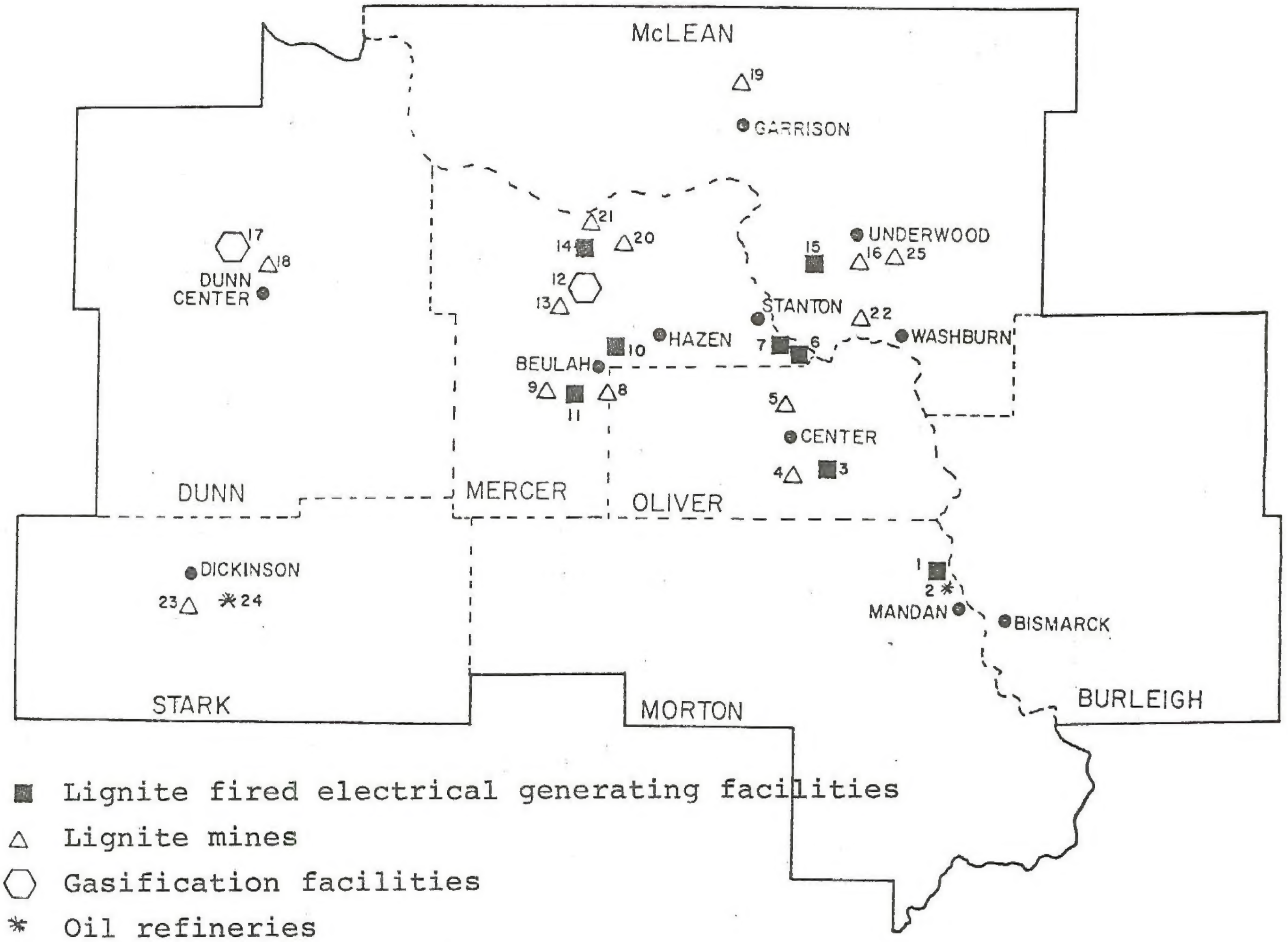
Of the ambient air contaminant sources presented in Table 8, five major area-wide sources have been proposed for construction and operation in the time period of the late 1980's. More specifically, these area-wide sources are all proposed lignite coal mining operations and include the Renner's Cove mine near Beulah, the Washburn mine near Underwood, the Nokota mine near Garrison, the Dakota Starr mine near Hazen, and the Underwood mine near Underwood.

The proposed point and area sources of ambient air contaminants in the seven county area have been divided into several phases of planned occurrence over time from the present through 1990. The air quality analysis was performed along the guidelines of the phases of development which have been termed Level 1, Level 2, and Level 3. Each level of development was considered for its environmental effect on air quality cumulatively with the existing area and point contaminant sources.

The major existing ambient air contaminant point sources and their emissions in pounds per hour are presented in Table 9.

FIGURE 1

LOCATIONS OF EXISTING AND PROPOSED
AIR CONTAMINANT SOURCES



SOURCE: North Dakota State Department of Health 1977

TABLE 9

MAJOR EXSISTING AMBIENT AIR CONTAMINANT POINT SOURCES TO THE STUDY AREA AND EMISSIONS IN POUNDS PER HOUR

Facility	Unit Number	Size (Mw)	Fuel	Emissions (lb/hr)[2]		
				TSP	SO_2	NO_x[3]
Heskett Power Plant	1	25	Lignite	6.1	490.0	148.0
	2	66	Lignite	11.7	1069.0	324.0
Leland Olds Power Plant	1	216	Lignite	19.0	3590.0	2924.0
	2	440	Lignite	100.0	7062.0	5780.0
UPA Power Plant	1	172	Lignite	125.0	1531.0	1225.0
UPA-CPA Coal Creek Power Plant	1	545	Lignite	127.0	6336.0	3696.0
	2	545	Lignite	127.0	6336.0	3696.0
Milton R. Young Power Plant	1	235	Lignite	16.0	5220.0	2800.0
	2	440	Lignite	113.0	3300.0	6375.0
MDU-Beulah Power Plant	1-5	13.5	Lignite	26.7	305.0	70.0
Amoco Oil Refinery	1	N.A.[1]	Fuel Oil & Gas	14.3	604.0	--
	2	N.A.	Coke	107.0	410.7	--
	3	7.5	Fuel Oil-Gas natural gas	45.0	478.2	--
	4	N.A.	Gas	1.2	2.4	--
	5	N.A.	Gas	1.9	13.5	--

SOURCE: North Dakota State Department of Health 1977

[1] Not applicable.
[2] Total emission rate of all effluent streams within the facility design.
[3] Total oxides of nitrogen emissions including nitrogen dioxide.

Table 10 presents the proposed Level 1 point and area sources with their expected emission contribution to the ambient air. The proposed Level 2 sources of emissions are presented in Table 11. Site specific information concerning proposed energy development required for performance of an air quality analysis for the proposed Level 3 phase of energy development was not available. The analysis of additional potential Level 3 coal development proposed areas is discussed in the projected ambient air quality effects section of this document.

TABLE 10

PROPOSED LEVEL 1 AMBIENT AIR CONTAMINANT POINT AND AREA SOURCES AND EXPECTED EMISSIONS

Point Sources: Facilities	Unit Number	Size (MW)	Fuel	Emissions (lb/hr) TSP	SO_2	NO_x 2/
Antelope Valley Power Plant	1	440	Lignite	175	4919	8,000
	2	440	Lignite	175	4919	8,000
Coyote Power Plant	1	440	Lignite	445	5330	15,200
Coal Gasification Plant (ANG) (American Natural Gas)	1	250×10^6 1/	Lignite	170	3078	2,100
Coal Gasification Plant (NGPL) (Natural Gas Pipeline Co.)	1	250×10^6	Lignite	397	2912	11,000

Area Sources: Facility	Coal Production (million tons/yr.)	Size 3/ (mi^2)	Emissions (tons/yr) 4/ TSP	SO_2 5/	NO_x 5/
American Natural Gas Company Mine (Coteau Properties)	9.4	2.40	696	--	--
Natural Gas Pipeline Company Mine (AMAX Coal Co.)	13.9	2.40	696	--	--
Glenharold Mine (Consolidation Coal Co.)	3.8	5.0	1929	--	--

SOURCE: North Dakota State Department of Health 1977

1/ Million standard cubic feet per day.

2/ Total oxides of nitrogen including nitrogen dioxide (NO_2).

3/ Estimate assuming maximum three year land surface exposure.

4/ Calculation based on a NDSDH study of 2 operating coal mines in western North Dakota.

5/ Mining operations do not constitute significant sources of SO_2 and NO_x.

TABLE 11

PROPOSED LEVEL 2 AMBIENT AIR CONTAMINANT POINT AND AREA SOURCES AND EXPECTED EMISSIONS

Point Sources: Facilities	Unit Number	Size (Mw)	Fuel	Emissions (lb/hr)		
				TSP	SO_2	NO_x 1/
Coyote Power Plant	2	440	Lignite	445	5335.0	3910.0

Area Sources: Facilities	Coal Production (Million tons/yr)	Size 2/ (mi^2)	Emissions(tons/yr)3/		
			TSP	SO_2 4/	NO_x 4/
Nokota Mine	6.6	1.8	575	--	--
Dakota Starr Mine	4.0	1.9	607	--	--
Renners Cove Mine	3.0	1.0	319	--	--
Washburn Mine	5.0	2.5	798	--	--
Underwood Mine	1.5	1.0	319	--	--

SOURCE: North Dakota State Department of Health 1977

1/ Total oxides of nitrogen including nitrogen dioxide (NO_x)
2/ Estimates based on total acres disturbed per year and assuming maximum three year land surface exposure
3/ Calculation based on a NDSDH study of 2 operating coal mines in western North Dakota.
4/ Mining operations do not constitute significant sources of SO_2 and NO_x

EXISTING ENVIRONMENT

Monitoring of air quality is necessary to determine if promulgated ambient air quality and PSD standards are being met. Monitoring of air quality is also necessary to determine trends in air quality as emission control requirements are met and growth and development occurs. The first air quality monitoring stations in North Dakota were established in January 1958 at Bismarck and near Foxholm. The Bismarck station was established to monitor total suspended particulates (TSP) in a commercial district and the Foxholm station was established to monitor TSP in a rural area for background levels. Since that time, the North Dakota State Department of Health (NDSDH) has established thirty-four (34) additional stations for a total of thirty-six (36). Table 12 presents a list of air quality parameters measured by levels of monitoring sites while Table 13 presents a list of the monitoring sites by sponsor, parameter level, date stated and type of site. Table 14 presents the monitoring sites and parameters measured within the seven county study area.

Fifteen (15) of the thirty-six (36) total sampling sites operated by the NDSDH have been added since 1974. In 1974, EPA established eight (8) sites in North Dakota under the Northern Great Plains Research Project (NGPRP). These sites were operated by PEDCo Environmental, Incorporated from September 1974 to September 1975. The sites were subsequently turned over to the NDSDH for continuing operation. In 1976, the Regional Environmental Assessment Program (REAP) of the North Dakota

TABLE 12

PARAMETERS MEASURED AT LEVEL I, LEVEL II, AND LEVEL III SITES

Parameter by Level	Level III	Level II	Level I
a) High volume sampling of total suspended particulates--on a six day schedule or a 12-day schedule	X	X	X
b) Sulfation rate--on a calendar month schedule	X	X	X
c) Sulfur dioxide and nitrogen dioxide bubbler samplers--on a six day schedule		X	X
d) Surface meteorology of wind speed, wind direction and temperature			X
e) Sulfur dioxide and oxides of nitrogen--continuously			X
f) Cascade sampler for particle sizing of particulates--on a six day schedule			X
g) Photochemical oxidants--continuously			X

Additional Parameters for Specific Sites
h) Membrane sampler for fine particulates --on a six day schedule
i) Precipitation of pH determination
j) Dustfall--on a calendar month schedule
k) Coefficient of haze -- continuously

SOURCE: North Dakota State Department of Health 1977

TABLE 13

NORTH DAKOTA STATE DEPARTMENT OF HEALTH AIR QUALITY MONITORING LOCATIONS

Location	Sponsor	Parameter Level	Date Started	Type of Site	Additional Parameters
Beulah	State	II	April 1974	Residential	j
Beulah	State	II	July 1974	Rural	
Bismarck	State	II	January 1958	Commercial	f, j, k
Bismarck	State	II	January 1975	Industrial	
Bismarck	REAP	I	December 1976	Rural	h, i
Bowman	NGPRP	III	September 1974	Rural	
Devils Lake	State	III	January 1970	Commercial	
Dickinson	State	III	January 1970	Commercial	
Dickinson	State	II	December 1975	Rural	
Fargo	State	II	January 1964	Commercial	k
Fargo	State	III	February 1971	Industrial	
Fargo	State	III	February 1971	Rural	
Garrison	NGPRP	III	September 1974	Rural	h
Grand Forks	State	III	January 1970	Commercial	
Grand Forks	State	III	January 1972	Residential	
Grassy Butte	REAP	II	September 1976	Rural	i
Halliday	REAP	II	October 1976	Rural	d, i
Jamestown	State	III	February 1974	Rural	
Jamestown	State	III	January 1972	Commercial	
Lake Tschida	REAP	II	September 1976	Rural	
Mandan	State	II	October 1970	Commercial	
Mandaree	REAP	III	August 1976	Rural	i
Medora	NGPRP	III	September 1974	Rural	
Minot	State	III	April 1967	Commercial	
Mott	NGPRP	II	September 1974	Commercial	
New England	REAP	III	August 1976	Rural	i
New Salem	REAP	III	August 1976	Rural	i
Parshall	NGPRP	III	September 1974	Rural	
Stanton	NGPRP	I	September 1974	Rural	j
Foxholm	State	III	January 1958	Rural	
Valley City	State	III	January 1972	Commercial	
Valley City	State	III	January 1974	Rural	
Wahpeton	State	III	October 1970	Residential	
Washburn	NGPRP	II	September 1974	Rural	
Williston	State	III	May 1970	Commercial	j

SOURCE: North Dakota State Department of Health 1977

TABLE 14

NORTH DAKOTA AIR QUALITY SAMPLING STATIONS WITHIN THE SEVEN COUNTY STUDY AREA AND AMBIENT AIR QUALITY CONTAMINANTS MEASURED AT EACH LOCATION

Ambient Air Contaminant Measured[1/]	Site Location											
	Dickinson Commercial	New Salem	Dickinson Rural	Mandan	Beulah Residential	Beulah Rural	Washburn	Halliday	Garrison	Stanton	Bismarck Rural	Bismarck Commercial
Total suspended particulates	X	X	X	X	X	X	X	X	X	X	X	X
Reactive Sulfur	X	X	X	X	X	X	X	X	X	X	X	X
Precipitation Collection for pH Studies		X						X			X	
Sulfur Dioxide Bubbler Method			X	X	X	X	X	X		X	X	X
Nitrogen Dioxide Bubbler Method			X	X	X	X	X	X		X	X	X
Settled Paritculate Collection						X	X	X		X		X
Surface Meteorology Station								X		X	X	
Cascade Particle Size Sampler										X	X	
Membrane Particle Sampler									X		X	
Sulfur Dioxide-Continuous Method										X	X	
Nitrogen Dioxide-Continuous Method										X	X	
Coefficient of Haze												X

SOURCE: North Dakota State Department of Health 1977

1/ X Signifies Ambient Air Contaminant Measured for Location Indicated

State Legislative Council, funded the NDSDH for establishment of seven baseline/monitoring sites.

Ambient Air Quality Contaminants Measured

Total suspended particulate (TSP) is analyzed by four different methods. The first method of TSP measurement is with the high volume sampler. Measured volumes of air are drawn through previously dried and weighed glass fiber filters at an average flow rate of approximately 50 cubic feet per minute (CFM). The filter used is an 8" x 10" sheet of flash-fired fiberglass (Type E) with a collection efficiency greater than 99% for particulates down to the 0.3 micron size range (μ). The sampling period is 24 hours from 12:00 midnight to 12:00 midnight once every six days or 12 days depending upon location. After each filter is weighed for total particulate, a 2 x 8" strip and a 2" diameter circle are removed. The strip is analyzed for particulate pH, suspended sulfates, nitrates, and fluorides. The circle is analyzed for gross beta radioactivity. The resulting data is statistically analyzed for arithmetic mean, geometric mean, and associated standard deviations.

A fractionating impactor (cascade impactor) is utilized to measure the size of the suspended particulate matter. The cascade impactor gives a measure of suspended particulates in five stages ranging from 3 microns to 0.5 micron. The mean particulate size for each stage is as follows: 3.1 μ, 2.1 μ, 1.5 μ, 0.9 μ, and 0.6 μ. Measured volumes (approximately 4.5 CFM) of air are drawn through the five impactor stages where particulates smaller than 0.5 μ are collected on an in-line glass fiber filter downstream from the final impactor stage. The sampling duration is 96 consecutive hours, on a 12:00 midnight to 12:00 midnight basis once every six days.

Dustfall, which is a measure of settled particulate, is determined using a 6-inch diameter by 12-inch deep container exposed to the ambient air for a one-month period. The units of measurement are short tons per square mile per month (tons/mi.^{2}/mo.).

Coefficient of haze is the fourth method by which TSP is measured in the ambient air. The measurement is performed with an instrument using a paper tape positioned between an air intake tube and a vacuum connection. Air is drawn through the filter for a period of three hours, at which time a new portion of tape is moved into position and sampling resumed. For the coefficient of haze measurement, the transmittance of light through both the filter and deposit and compared with transmittance through a clean portion of the filter. A coefficienct of haze measurement is routinely reduced to coefficient of haze per one thousand linear feet of air passing through the filter tape by dividing the unreduced coefficient of haze value by the number of thousands of feet of ambient air actually drawn in the test.

Sulfur dioxide (SO_2) is sampled by both the bubbler method and a continuous analyzer. Fifty milliliters of absorbing reagent are placed in the bubbler tube and sample air is drawn through the solution at 200 cubic centimeters per minute (cc/m) for 24 hours. SO_2 reacts with the absorbing solution to form a stable complex which is analyzed by the pararosanaline method. Fourteen bubblers are presently in operation with nine located within the seven county study area.

The SO_2 continuous sampling method utilizes the (coulometric) method. The coulometric method utilizes I_2/Br_2 gas in aqueous solution which reacts with the sulfur dioxide. The amount of I_2/Br_2 in solution (which is continuously regenerated) is monitored by the measurement of current between two electrodes. The current is then measured, amplified and recorded. The process of I_2/Br_2 depletion and regeneration is continuous and when equilibrium conditions have been restored, a background level is recorded.

Oxides of nitrogen (NO_x) are sampled by both the bubbler method (sodium arsenite) and the continuous method. The sodium arsenite method is specific for NO_x. The continuous analysis for NO_x is a chemiluminescence method. In this method, nitric oxide and electronically generated ozone react to emit small amounts of light which are detected, amplified and recorded to continuously reflect the contaminant levels in the air.

Reactive sulfur (sulfation rate) is determined by the use of a Huey sulfation plate. This is a 2" in diameter petri dish, coated with a thin layer of lead dioxide which is exposed to the sulfur oxides in the ambient air for a period of one month. The sulfur compounds in the air react with the lead dioxide to form lead sulfate. The units for reactive sulfur are milligrams of sulfur trioxide (SO_3) per one hundred square centimeters per day (mg $SO_3/100\ cm^2/day$). The instruments used for sampling the various air contaminants, sampling intervals, and techniques are summarized on Table 15.

Another group of contaminants found in the ambient air are photochemical oxidants. The best known of this group of compounds is ozone (O_3). Ozone is a highly reactive and toxic form of oxygen (O_2) and is important as the precursor for the oxidation of many chemically reactive air contaminants.

The hydrocarbons are organic compounds which combine with many additional elements such as oxygen, nitrogen and chlorine to form complex organic compounds. The hydrocarbons of concern are those gas-phase hydrocarbons which may be encountered in urban atmospheres as they react with nitrogen dioxide in the presence of sunlight to form photochemical oxidants. Of special interest are those hydrocarbons emitted into the atmosphere as contaminants by technological sources such as refineries and automobile emissions.

TABLE 15

AMBIENT AIR QUALITY MONITORING EQUIPMENT

Air Contaminant	Sampling Instrument	Sampling Interval	Analytical Technique
Total Suspended Particulate (TSP)	Standard Hi Vol Sampler	24 hours	Gravimetric
Reactive Sulfur (Sulfation rate)	Huey Sulfation Plates	1 month	Turbidimetric
Sulfur Dioxide (SO_2)	Continuous Sampler	Automated Continuous	Coulometric
	Bubbler Sampler	24 hours	Pararosanaline
Nitrogen Dioxide (NO_2)	Continuous Sampler	Automated Continuous	Chemiluminescence
	Bubbler	24 hours	Sodium Arsenate
Nitrogen Oxide (NO)	Continuous Sampler	Automated Continuous	Chemiluminescence
Dustfall	Standard Dustfall Container	1 month	Gravimetric
Suspended Particulate Size	NASN Cascade Impactor	96 hours every 6 days	Gravimetric
Ozone	Continuous Sampler	Automated Continuous	Chemiluminescence

SOURCE: North Dakota State Department of Health 1976

The most widely distributed and most commonly occurring air contaminant is carbon monoxide (CO). The total emissions of carbon monoxide to the atmosphere nationally exceed those of all other contaminants combined. The primary source of carbon monoxide is the incomplete combustion of fossil fuels.

The final ambient air contaminant to be addressed is hydrogen sulfide (H_2S). Hydrogen sulfide is a highly toxic gaseous compound easily identified by its distinctive rotten egg odor. The major sources of hydrogen sulfide within the State of North Dakota are associated with sour natural gas wells.

Existing Air Quality in the Study Area

The sources of particulates, sulfur dioxide, and oxides of nitrogen in the seven county study area are classified in two ways. These two classifications are area-wide sources and point sources. Area sources include unpaved roads, agriculture, construction, highway vehicle traffic both on and off highways, mining, and fossil fuel combustion. Point sources are primarily industrial and commercial processes such as fossil fuel refining, electrical power generation, and agricultural related industries.

The focus of the air quality analysis within the study area was directed toward the environmental effects of the addition of major point sources of air contaminants and their associated mining operations. Existing area source contaminant contributions to the ambient air in the study area constitute an increment of the measured background upon which the air quality analysis was performed. The particulate contribution to the ambient air in the study area for the counties of McLean, Mercer, Oliver and Dunn in 1975 are presented in Figures 2 through 5. Figure 6 is a composite of total area source particulate contributions.

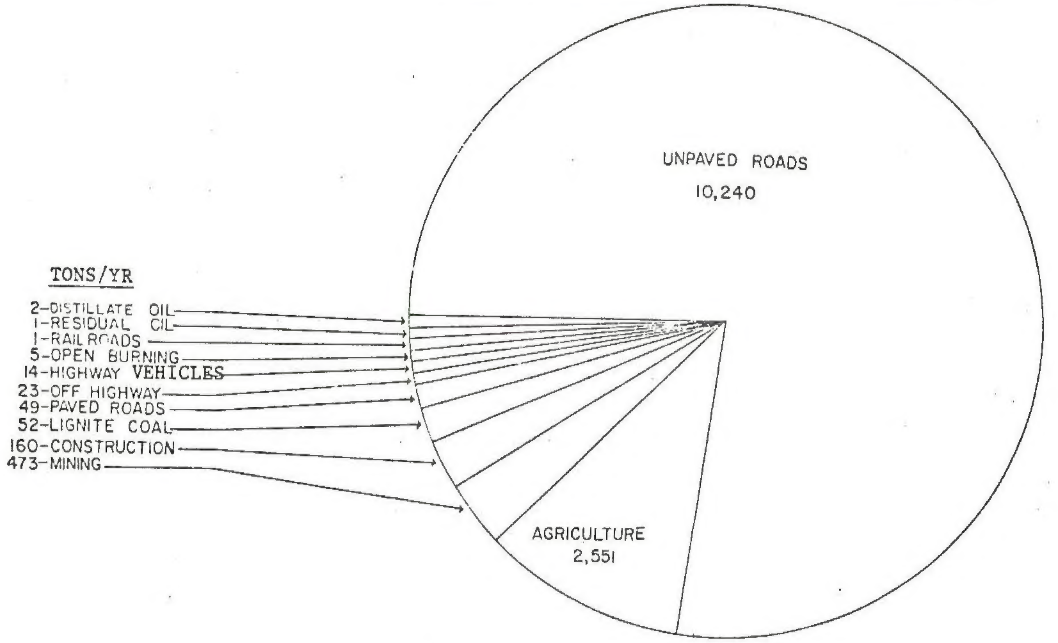
Measured background data concerning values for particulates in western North Dakota, including the seven county study area, for the years 1970 through 1976 is presented in Figure 7. This data was compiled from records from the North Dakota State Department of Health air quality monitoring network. The 1975 and 1976 data is presented in Figures 8 and 9, which are isolines maps of western North Dakota showing the measured annual geometric mean concentrations of total suspended particulate matter in the seven county study area. Figure 10 presents a breakout of the air quality monitoring network annual geometric mean data by urban and rural sampling sites for the years 1970 through 1976.

Table 16 presents individual maximum and minimum total suspended particulate readings from each air quality monitoring station in western North Dakota. The North Dakota ambient air quality standard for maximun 24-hour concentrations of total suspended particulates has also been indicated on the table. This standard is 150 $\mu g/m^3$, maximum 24-hour ambient air

FIGURE 2

1975 AREA SOURCE PARTICULATE EMISSIONS
OLIVER COUNTY

TOTAL EMISSIONS 13,535 tons/yr.

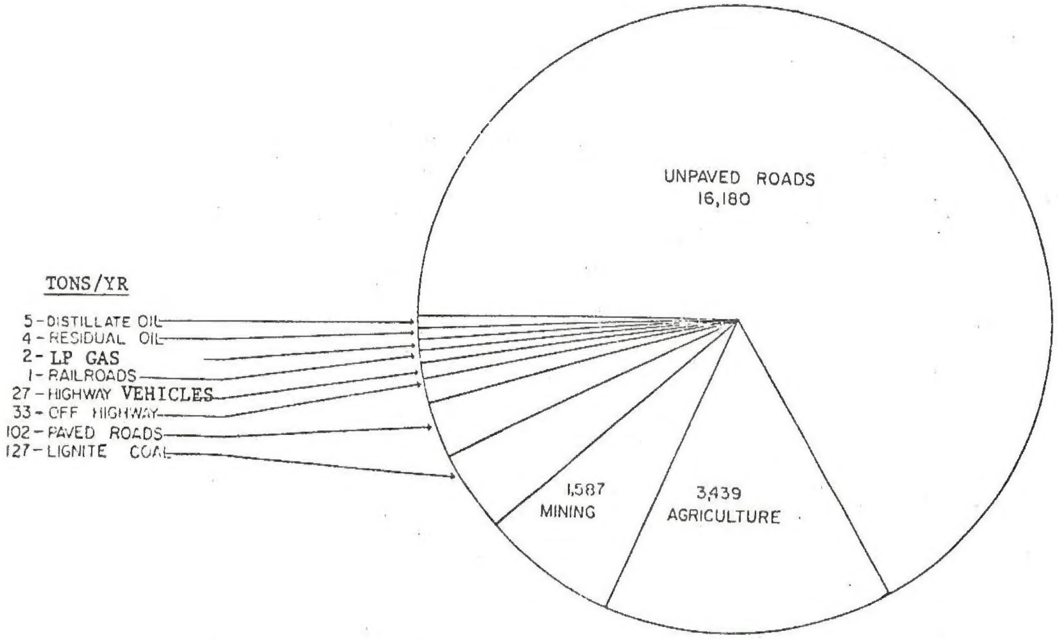


%	SOURCE
<0.1	DISTILLATE OIL
<0.1	RESIDUAL OIL
0.0	NATURAL GAS
<0.1	RAILROADS
<0.1	OPEN BURNING
0.0	LP GAS
0.4	LIGNITE COAL
0.1	OFF HIGHWAY
0.1	HIGHWAY VEHICLES
0.3	PAVED ROADS
18.8	AGRICULTURE
75.6	UNPAVED ROADS
1.2	CONSTRUCTION
3.5	MINING

FIGURE 3

1975 AREA SOURCE PARTICULATE EMISSIONS
MERCER COUNTY

TOTAL EMISSIONS 21,507 tons/yr.



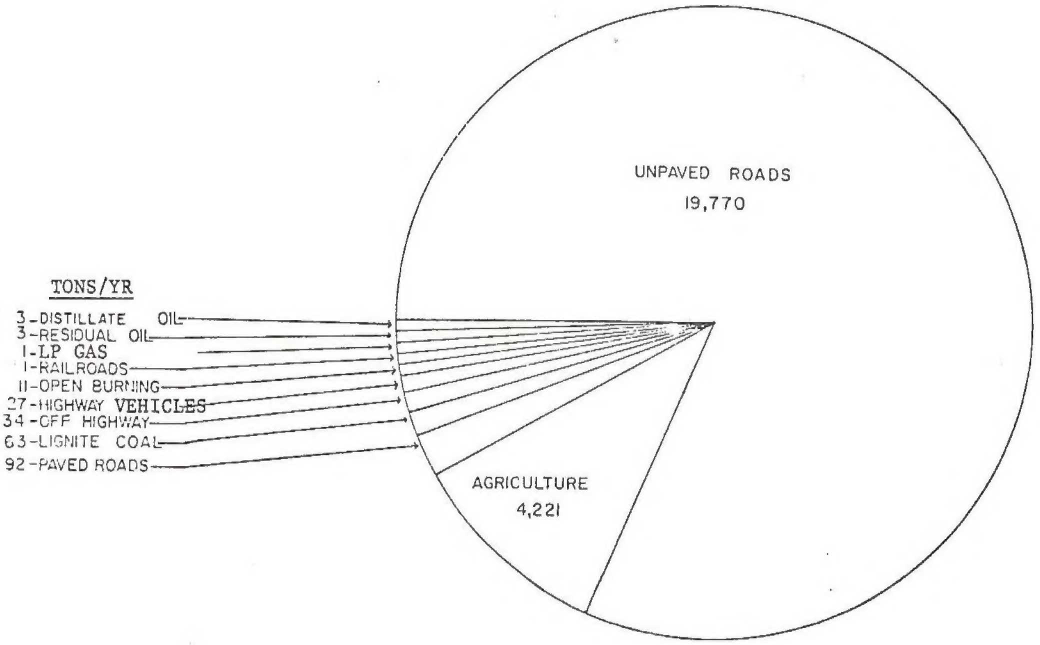
%	SOURCE
<0.1	DISTILLATE OIL
<0.1	RESIDUAL OIL
0.0	NATURAL GAS
<0.1	RAILROADS
0.0	OPEN BURNING
<0.1	LP GAS
0.6	LIGNITE COAL
0.1	OFF HIGHWAY
0.1	HIGHWAY VEHICLES
0.4	PAVED ROADS
16.0	AGRICULTURE
75.2	UNPAVED ROADS
0.0	CONSTRUCTION
0.7	MINING

SOURCE: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

FIGURE 4

1975 AREA SOURCE PARTICULATE EMISSIONS
DUNN COUNTY

TOTAL EMISSIONS 24,226 tons/yr.

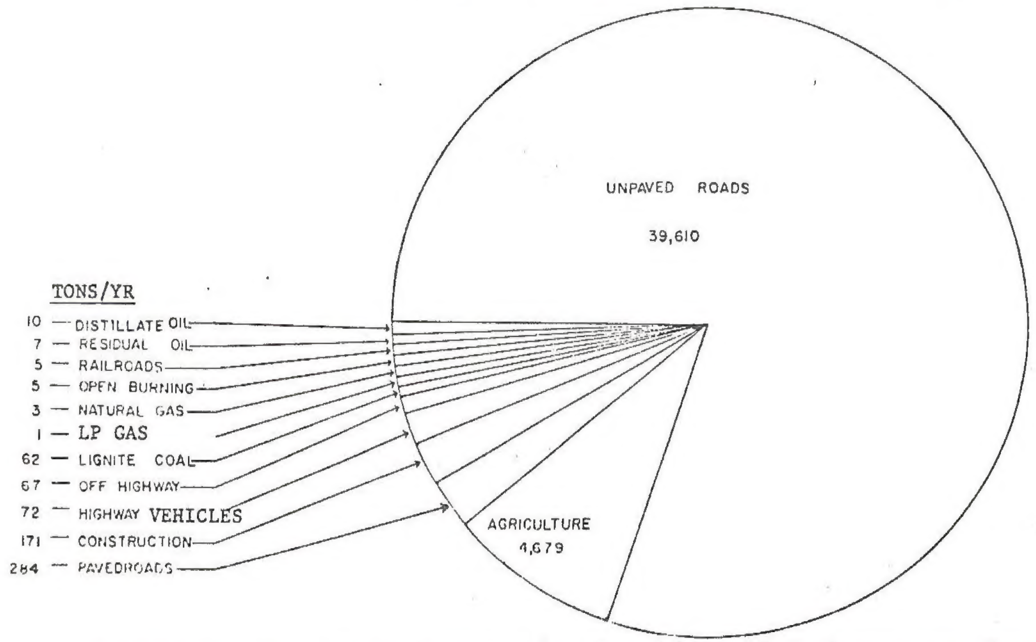


%	SOURCE
<0.1	DISTILLATE OIL
<0.1	RESIDUAL OIL
0.0	NATURAL GAS
<0.1	RAILROADS
<0.1	OPEN BURNING
<0.1	LP GAS
0.3	LIGNITE COAL
0.1	OFF HIGHWAY
0.1	HIGHWAY VEHICLES
0.4	PAVED ROADS
17.4	AGRICULTURE
81.6	UNPAVED ROADS
0.0	CONSTRUCTION
0.0	MINING

FIGURE 5

1975 AREA SOURCE PARTICULATE EMISSIONS
McLEAN COUNTY

TOTAL EMISSIONS 44,976 tons/yr.

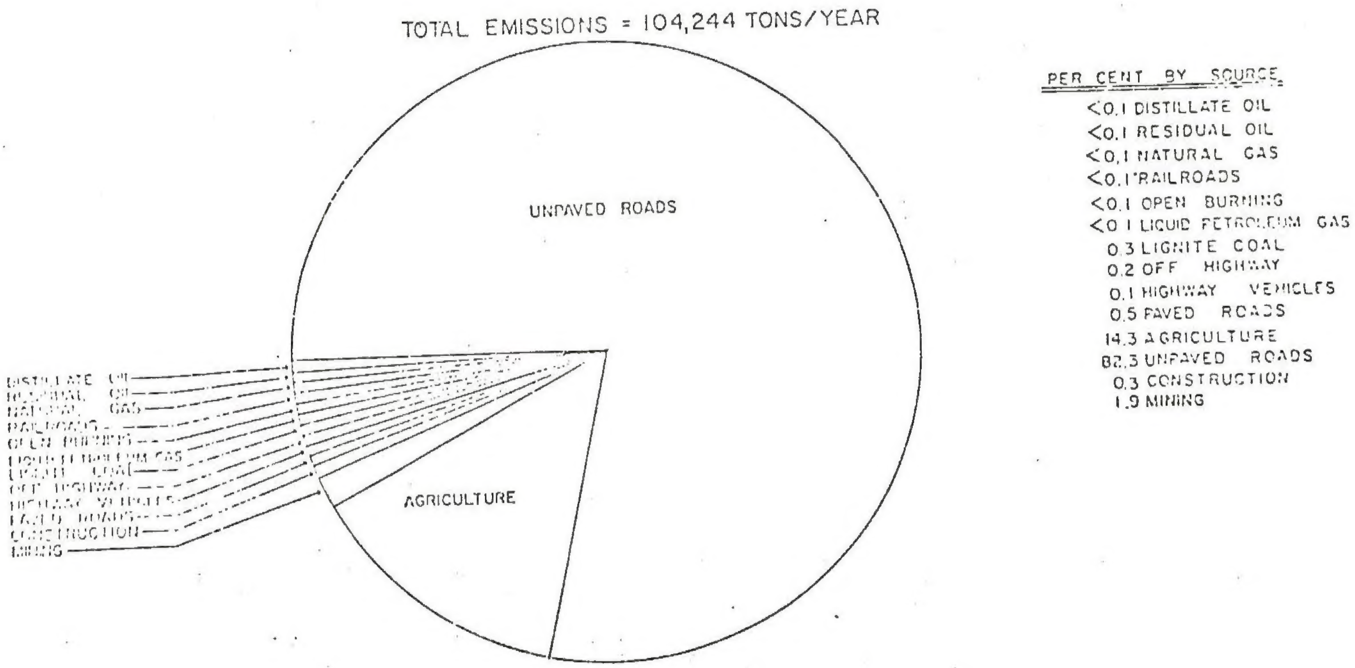


%	SOURCE
< 0.1	DISTILLATE OIL
< 0.1	RESIDUAL OIL
< 0.1	NATURAL GAS
< 0.1	RAILROADS
< 0.1	OPEN BURNING
< 0.1	LP GAS
0.1	LIGNITE COAL
0.1	OFF HIGHWAY
0.2	HIGHWAY VEHICLES
0.6	PAVED ROADS
10.4	AGRICULTURE
888	UNPAVED ROADS
0.3	CONSTRUCTION
0.0	MINING

SOURCE: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

FIGURE 6

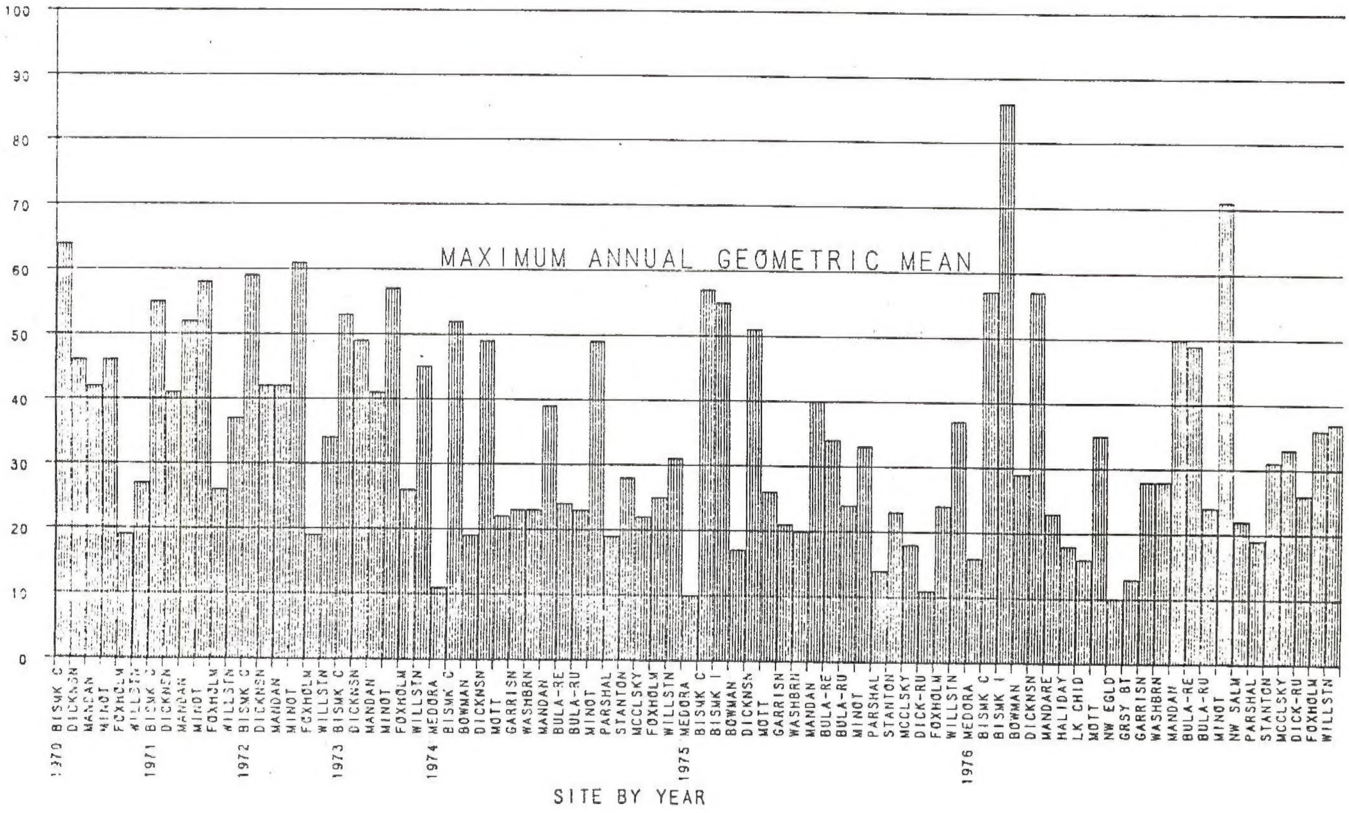
1975 AREA SOURCE TOTAL SUSPENDED PARTICULATE (TSP) EMISSIONS FOR OLIVER, MERCER, DUNN AND McLEAN COUNTIES WITHIN THE STUDY AREA



Source: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

FIGURE 7

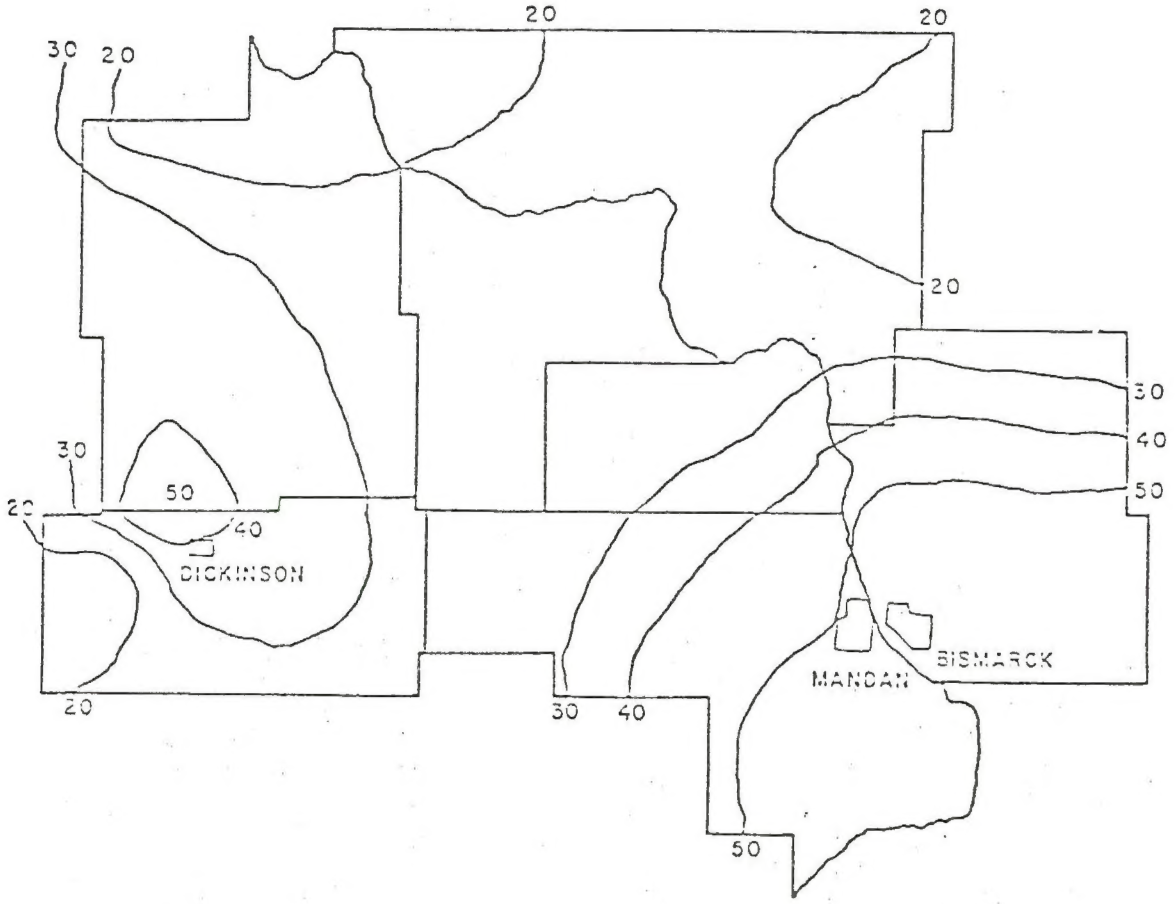
TOTAL SUSPENDED PARTICULATE ANNUAL GEOMETRIC MEAN
ALL MONITORING SITES 1970 - 1976



SOURCE: North Dakota State Department of Health 1976

FIGURE 8

TOTAL SUSPENDED PARTICULATES IN THE SEVEN COUNTY STUDY AREA - 1975

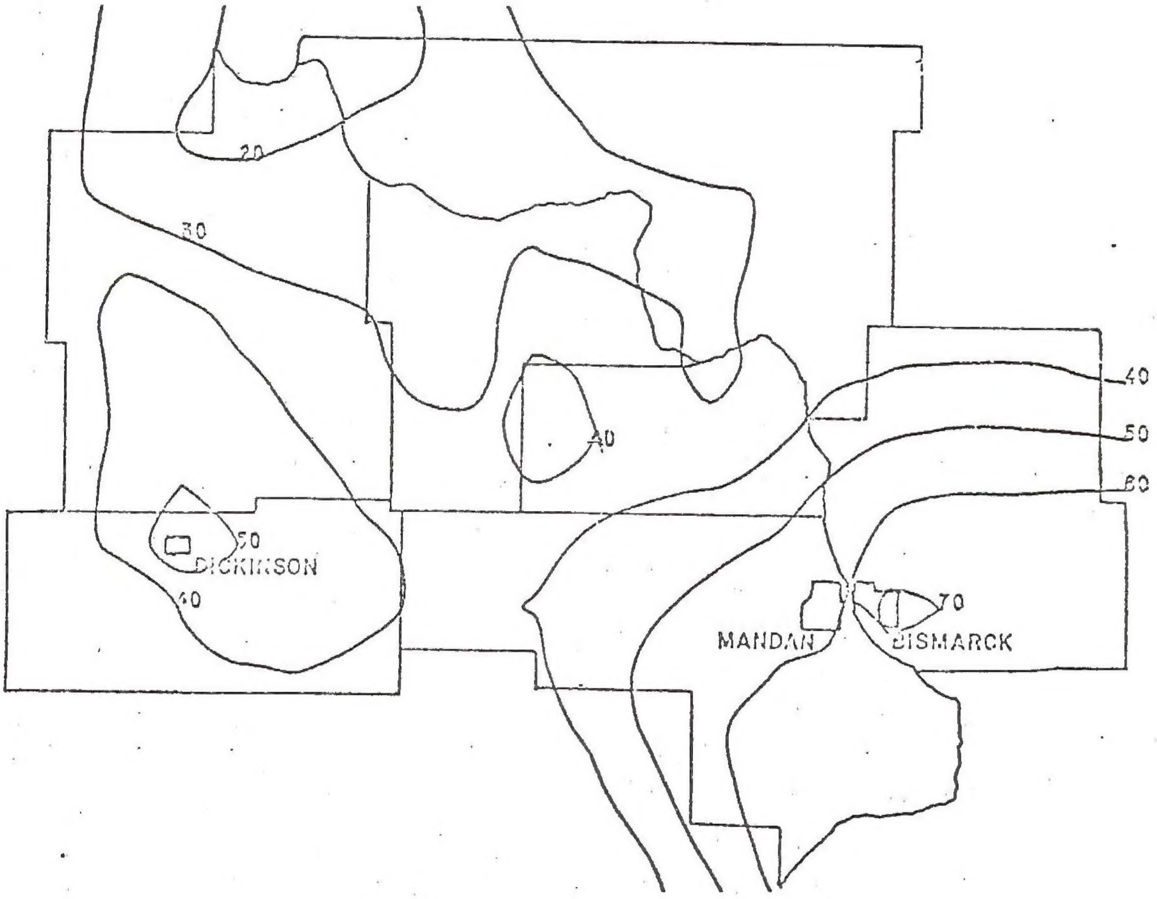


SOURCE: North Dakota State Department of Health 1977

NOTE : All values in micrograms per cubic meter of air ($\mu g/m^3$) annual geometric mean from measured concentrations

FIGURE 9

TOTAL SUSPENDED PARTICULATES IN THE SEVEN COUNTY STUDY AREA - 1976

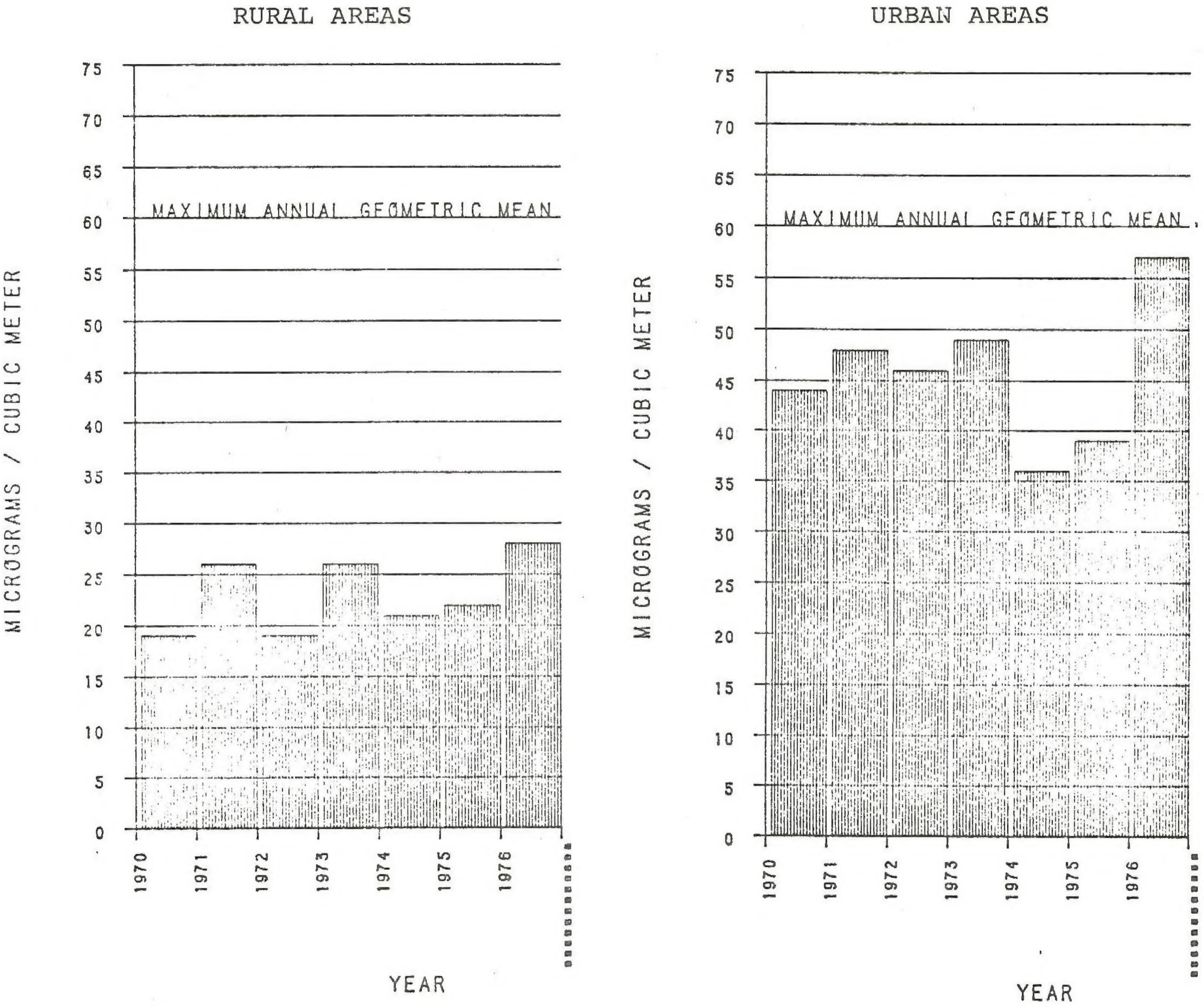


SOURCE: North Dakota State Department of Health

NOTE: All values in micrograms per cubic meter of air ($\mu g/m^3$) annual geometric mean from measured concentrations.

FIGURE 10

TOTAL SUSPENDED PARTICULATE ANNUAL GEOMETRIC MEAN
1970 - 1976



SOURCE: North Dakota State Department of Health 1976

TABLE 16

24-HOUR TOTAL SUSPENDED PARTICULATE (TSP) CONCENTRATIONS IN THE STUDY AREA 1970-1976 IN MICROGRAMS PER CUBIC METER

Monitoring Site	Year	Recorded Value ($\mu g/m^3$) Max.	Min.	Number of Violations[1] Per Year
Bismarck - Commercial	1976	373	8	3
	1975	201	9	1
	1974	134	2	
	1973	158	22	
	1972	406	17	
	1971	147	29	
	1970	136	37	2
Bismarck - Industrial	1976	397	8	18
	1975	232	10	1
Dickinson - Commercial	1976	116	16	
	1975	185	23	
	1974	156	23	
	1973	149	16	
	1972	105	3	
	1971	98	11	
	1970	126	8	
Dickinson - Rural	1976	76	4	
Mandaree	1976	61	8	
Halliday	1976	55	8	
Grassy Butte	1976	49	5	
Garrison	1976	176	4	
	1975	278	2	1
	1974	112	7	
Washburn	1976	127	3	
	1975	92	2	
	1974	128	8	
Mandan	1976	287	4	
	1975	394	15	
	1974	102	12	
	1973	116	18	
	1972	112	15	
	1971	100	18	
	1970	83	11	
New Salem	1976	61	5	
Beulah - Residential	1976	148	15	
	1975	151	12	
	1974	1781	2	1
Beulah - Rural	1976	81	7	
	1975	171	3	
	1974	488	1	
Stanton	1976	150	5	
	1975	99	7	
	1974	185	6	1

SOURCE: North Dakota State Department of Health 1977

[1] The North Dakota 24-hour Ambient Air Quality Standard for Particulates is 150 $\mu g/m^3$ of air as a maximum allowable concentration not to be exceeded more than once per year. A violation occurs when the standard is exceeded.

concentration, not to be exceeded more than once per year. The monitoring sites in the study area where the 24-hour ambient air TSP standard has been exceeded in 1975 is presented in Table 17.

Figure 11 presents total suspended particulate annual geometric mean concentrations measured at Foxholm from 1958 through 1976. This data is considered representative of the TSP ambient air concentration normally observed throughout rural western North Dakota. As can be seen from the figure, there is a wide variation in values from year to year. These variations may be attributed to such factors as the occurrence of wet and dry years in terms of precipitation, changing patterns of agricultural activity in the area, and a host of other natural and human-induced factors. Because of such influences, it is not possible at this time to establish a valid trend concerning change in the ambient air concentrations of TSP over time in the rural areas of western North Dakota.

The background levels of ambient air dustfall (settled particulate) have not been extensively measured in the study area. Figure 12 is a presentation of a 3-month sliding average for dustfall measured at Bismarck from 1970 through 1976. The dashed-line is a least mean squares trend analysis line showing the seven-year trend in ambient air dustfall measurements. Tables 18 and 19 present dustfall measurements taken in Oliver and Mercer Counties during 1976 as part of a research project concerning trace elements currently being conducted by the North

TABLE 17

TOTAL SUSPENDED PARTICULATES SITES EXCEEDING 150 MICROGRAMS PER CUBIC METER AMBIENT AIR QUALITY STANDARD IN 1975

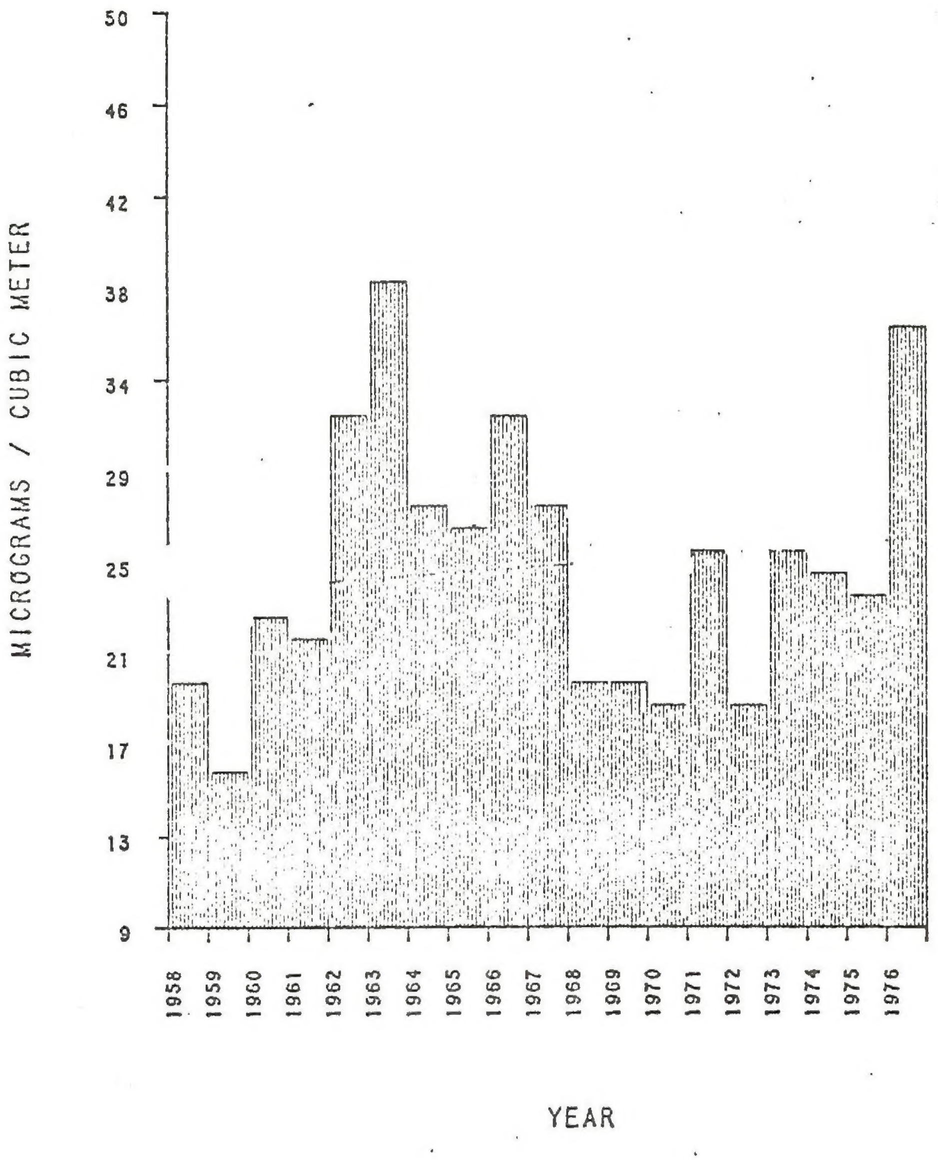
SITE	MONTH	CONCENTRATION (μg/m^3) 1/
Bismarck - Commercial	May	201
	July	182
Bismarck - Industrial	May	176
	July	232
Dickinson - Commercial	December	185
Mandan	January	394
Beulah - Residential	January	151
Beulah - Rural	July	171
Garrison	February	275
Stanton	October	185

SOURCE: North Dakota State Department of Health 1976

1/ Micrograms per cubic meter of air (μg/m^3)

FIGURE 11

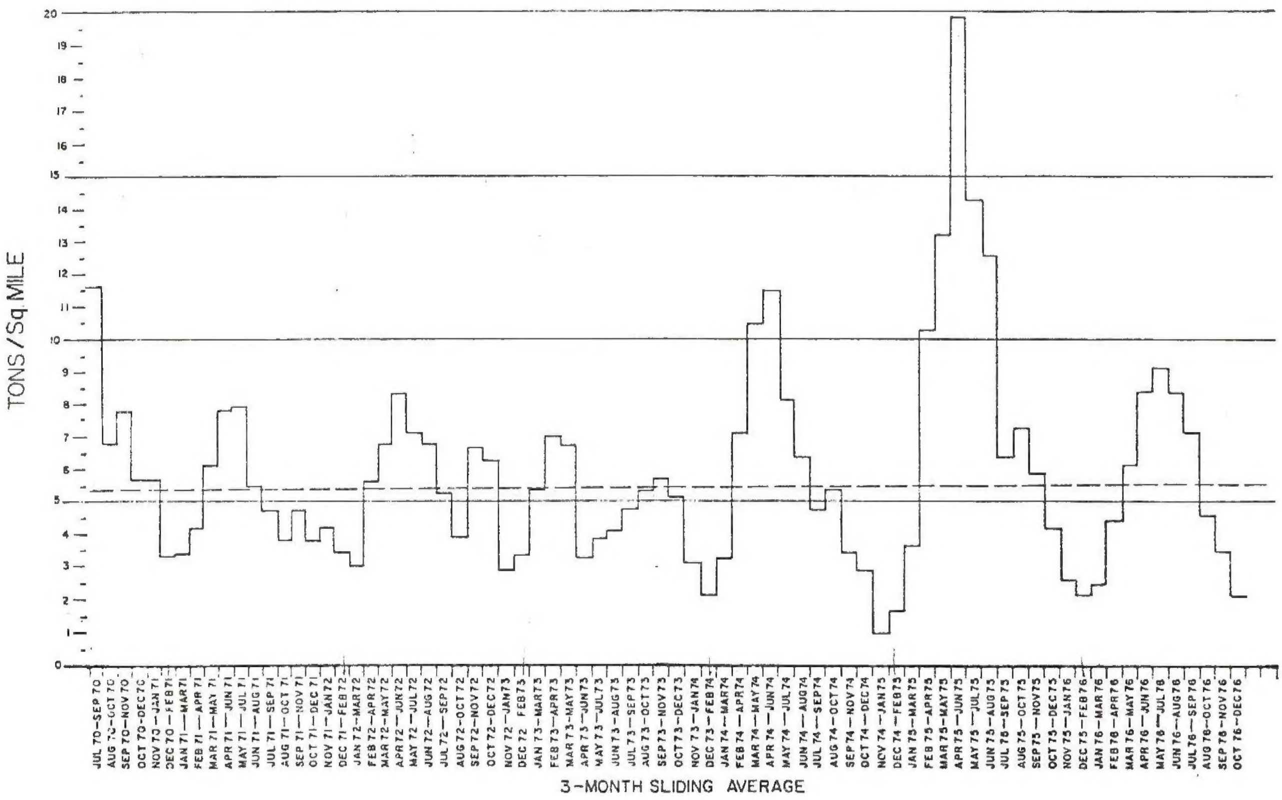
TOTAL SUSPENDED PARTICULATE ANNUAL
GEOMETRIC MEAN, FOXHOLM SITE 1958 - 1976



SOURCE: North Dakota State Department of Health 1976

FIGURE 12

SETTLED PARTICULATE (DUSTFALL) 1970 - 1976
BISMARCK COMMERCIAL SITE



SOURCE: North Dakota State Department of Health 1976

TABLE 18

AVERAGE DUSTFALL BY MONTH
OLIVER COUNTY 1976

Month	Tons/mi^2/month[1/]
January	2.15
February	2.80
March	5.24
April	7.88
May	9.12
June	17.12
July	9.08
August	7.26
September	13.77
October	7.90
November	4.19
December	2.90

SOURCE: Trace Element Project, North Dakota State Department of Health 1977

[1/] Average from 20 rural sampling sites

TABLE 19

AVERAGE DUSTFALL BY MONTH
MERCER COUNTY - 1976

Month	Tons/mi^2/month[1/]
January	2.93
February	3.50
March	5.11
April	13.61
May	12.14
June	18.22
July	16.43
August	7.78
September	5.57
October	5.50
November	3.43
December	1.72

SOURCE: Trace Element Project, North Dakota State Department of Health 1977

1/ Average from 22 rural sampling sites

Dakota State Department of Health. Due to the limited data concerning rural background dustfall available at this time, an analysis of trends in relation to various activities such as agriculture and energy development in the study area cannot be undertaken.

Coefficient of haze is a measurement of the soiling potential and visibility qualities of the ambient atmosphere. Figure 13 presents the coefficient of haze data collected at Bismarck for the years 1971 through 1976. The data is presented as COHS per 1000 linear feet. This is defined as "the quantity of light-scattering solids in the air producing an optical density of 0.01 when measured by light transmittance.

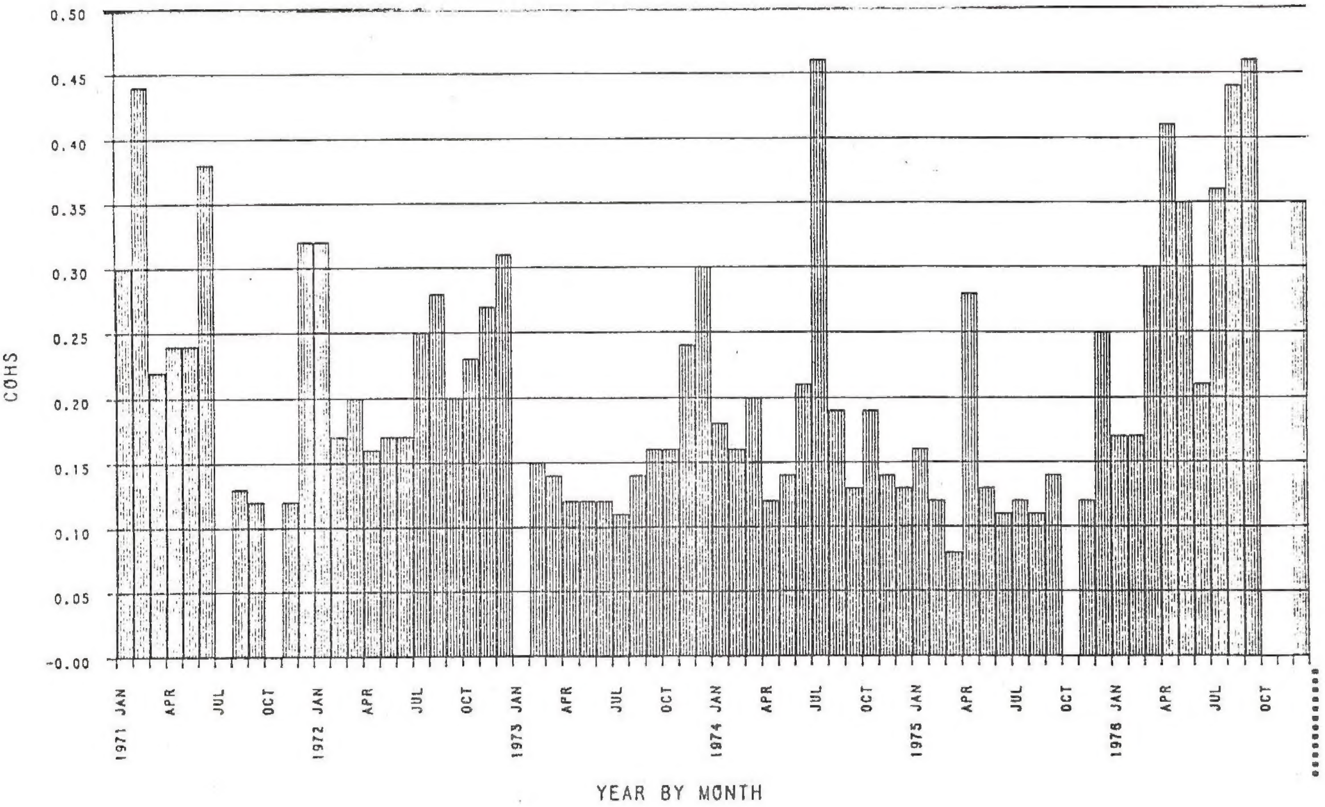
In more general terms, coefficient of haze is an estimate of the capabilities of particulates in the atmosphere to cause soiling of buildings, walls, furniture and so on. Established ranges of COHS units and their soiling ratings are as follows:

COHS/1000 linear ft.	Rating
0.-0.9	light
1.0-1.9	moderate
2.0-2.9	heavy
3.0-3.9	very heavy

The North Dakota Ambient Air Quality Standard for Coefficient of Haze has been established at 0.4 COHS per 1000 linear feet as a

FIGURE 13

SOIL INDEX (COHS) 1971 - 1976
BISMARCK COMMERCIAL SITE



SOURCE: North Dakota State Department of Health 1976

NOTE: units expressed as a monthly arithmetic mean maximum annual geometric mean. In reference to the soiling rating table, the standard for permissible COHS level is well within the light soiling range. An annual geometric mean composite of COHS data from Bismarck for the years 1971 through 1976 is presented in Figure 14. The current North Dakota Ambient Air Quality Standard for COHS is also displayed to show the relationship of the measured values for each year to the permissible coefficient of haze level.

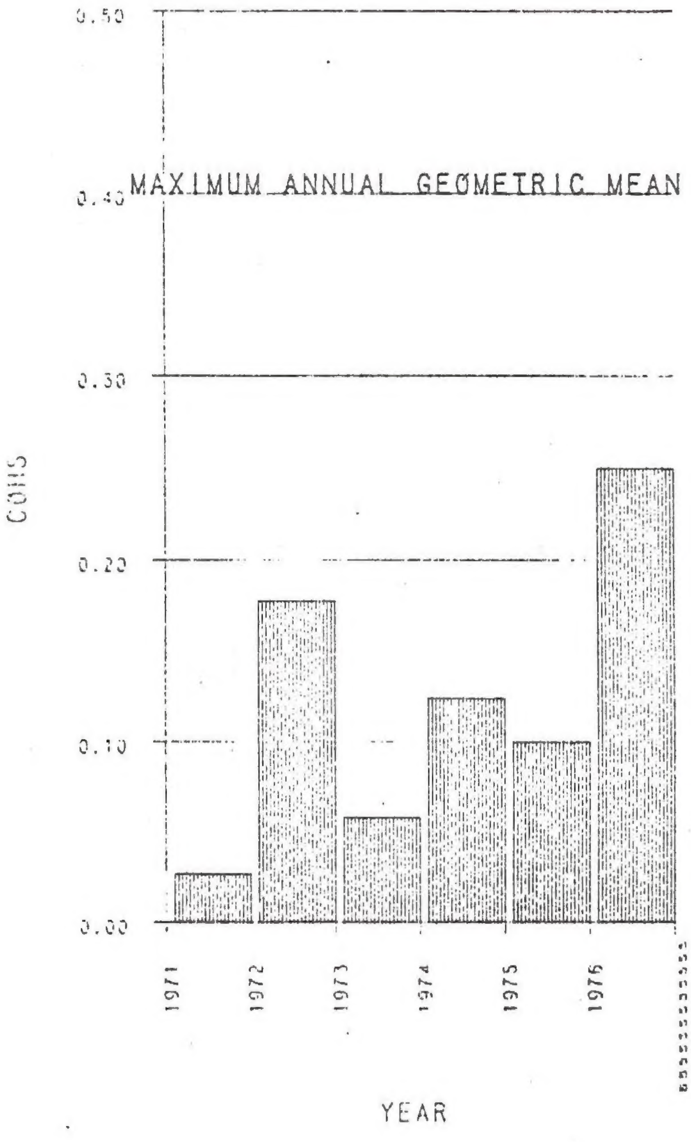
Total suspended particulate matter in the ambient air is defined as separate particles of microscopic size in a gaseous media. The measurement of the size ranges of these particles in the ambient air is an important parameter in accessing potential adverse impacts of total suspended particulate matter. For example, suspended particulates in the submicron size ranges (less than one micron) may interfere with normal human and animal respiratory function resulting in potential adverse health effects (Perkins 1974).

Data concerning particle size fractionation of total suspended particulate matter has been obtained at two locations within the study area for the years 1975 and 1976. The locations and corresponding data are shown in Figures 15 and 16.

Sulfur dioxide contribution to the ambient air from area sources in the study area has been determined for the year 1975. The total emissions of SO_2 in tons per year and the respective area

FIGURE 14

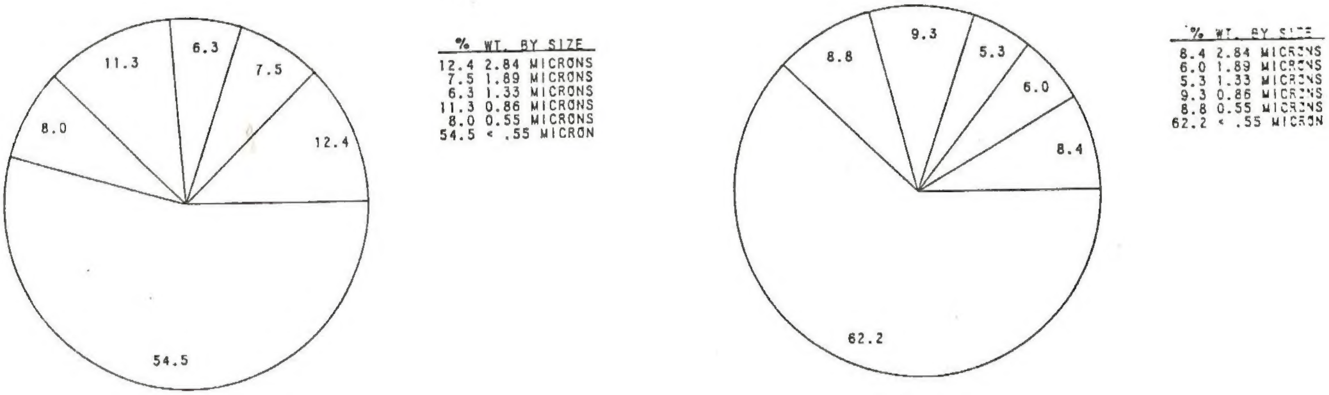
ANNUAL GEOMETRIC MEAN SOIL INDEX BISMARCK-COMMERCIAL (COHS)



SOURCE: North Dakota State Department of Health 1976

FIGURE 15

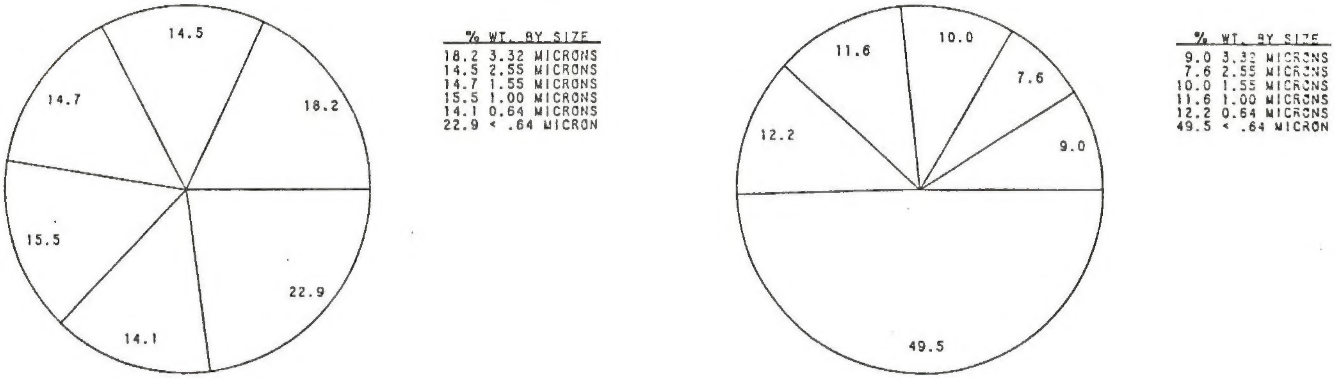
SUSPENDED PARTICULATE SIZE BY WEIGHT, ANNUAL ARITHMETIC MEAN
BISMARCK COMMERCIAL SITE



1975 1976

FIGURE 16

SUSPENDED PARTICULATE SIZE BY WEIGHT, ANNUAL ARITHMETIC MEAN
STANTON SITE



1975 1976

SOURCE: North Dakota State Department of Health 1976

source percentage contribution to the total for Oliver, Mercer, McLean and Dunn Counties is presented in Figures 17 through 20. A composite of this data is shown in Figure 21.

Sulfur dioxide ambient air concentrations have been measured at several locations throughout the study area. These locations are: Bismarck, Mott, Washburn, Beulah, and Stanton. The annual arithmetic mean concentrations for sulfur dioxide in micrograms per cubic meter by the bubbler method for all of these locations in 1975 is presented in Table 20. The maximum 24-hour concentrations in micrograms per cubic meter occurring at these locations within the study area in 1975 is shown in Table 21. Table 22 presents data collected at Stanton as hourly maximum concentrations for any given month in micrograms per cubic meter during 1975.

All of the annual arithmetic mean averages for sulfur dioxide recorded at these locations in 1975 are within the State and Federal Ambient Air Quality Standards for permissible concentrations of SO_2. As discussed earlier, the annual North Dakota Ambient Air Quality Standard for SO_2 is 60 $\mu g/m^3$ and the annual Federal Primary Standard is 80 $\mu g/m^3$. The maximum 24-hour and hourly permissible levels of SO_2 also are within the State Standard of 260 $\mu g/m^3$ maximum 24-hour and 715 $\mu g/m^3$ maximum one-hour concentration. At the present time, there is no Federal Primary or Secondary Standard for maximum one-hour allowable concentrations of SO_2. However, a maximum

FIGURE 17

1975 AREA SOURCE SULFUR DIOXIDE EMISSIONS
OLIVER COUNTY
TOTAL EMISSIONS 61 Tons/yr.

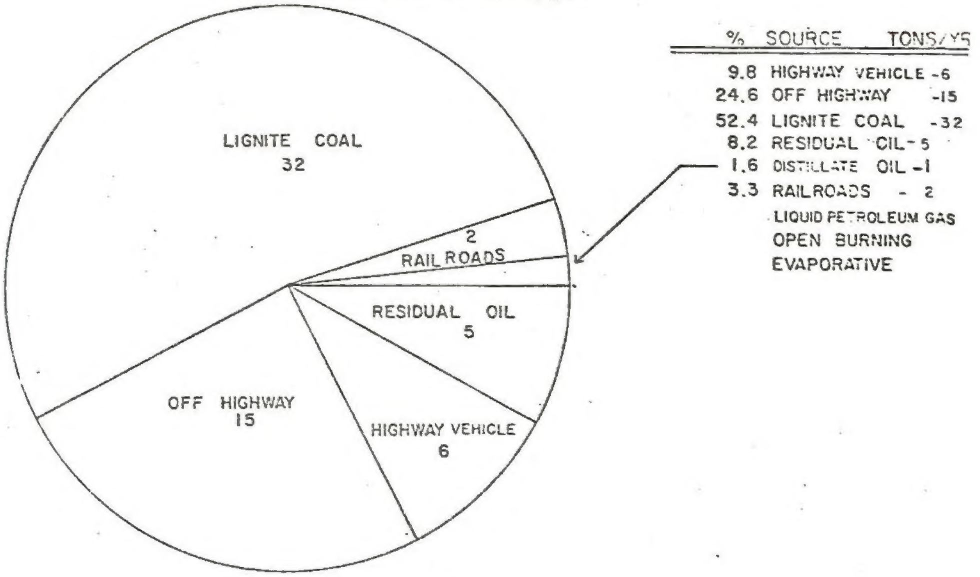
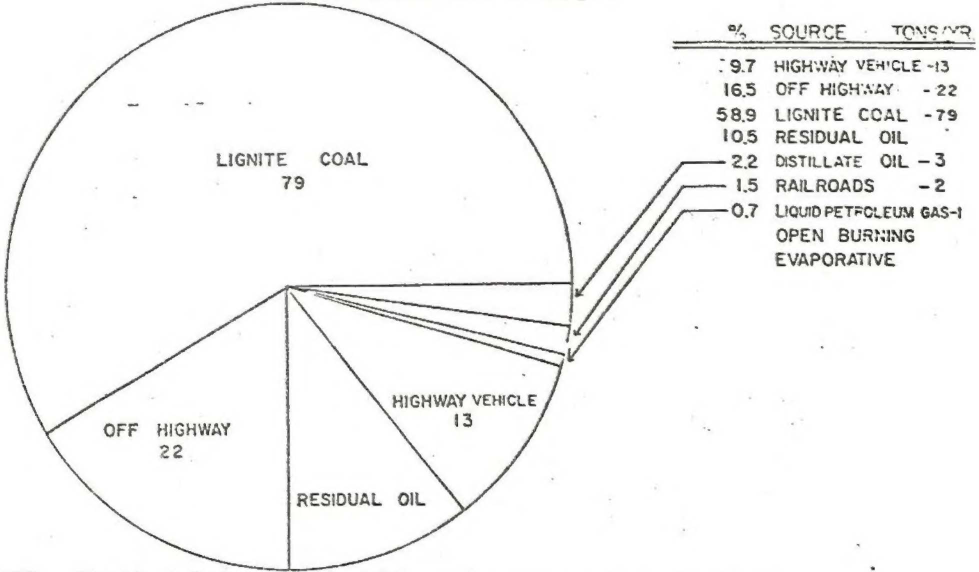


FIGURE 18

1975 AREA SOURCE SULFUR DIOXIDE EMISSIONS
MERCER COUNTY
TOTAL EMISSIONS 134 Tons/yr.



SOURCE: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

FIGURE 19

1975 AREA SOURCE SULFUR DIOXIDE EMISSIONS
DUNN COUNTY
TOTAL EMISSIONS 89 Tons/yr.

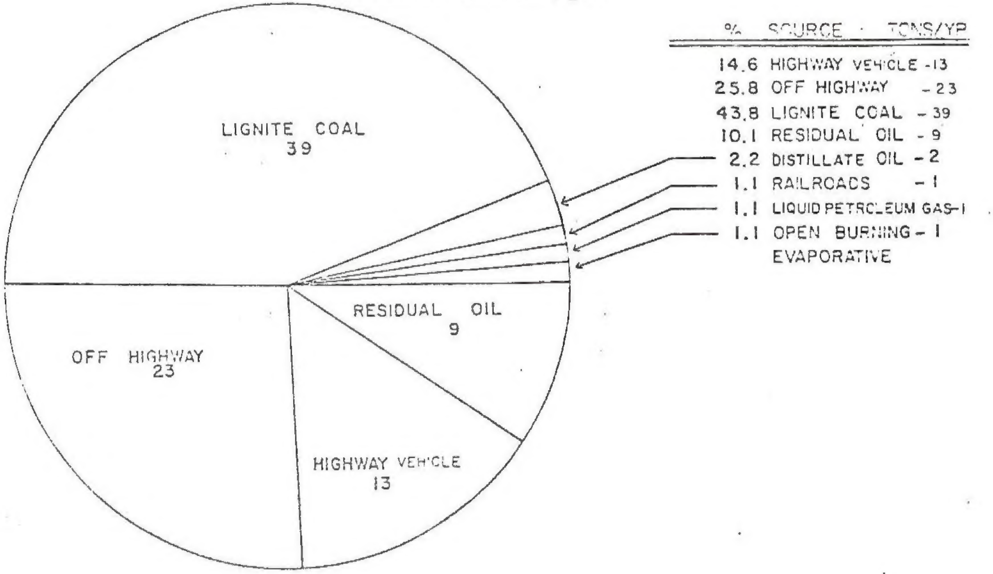
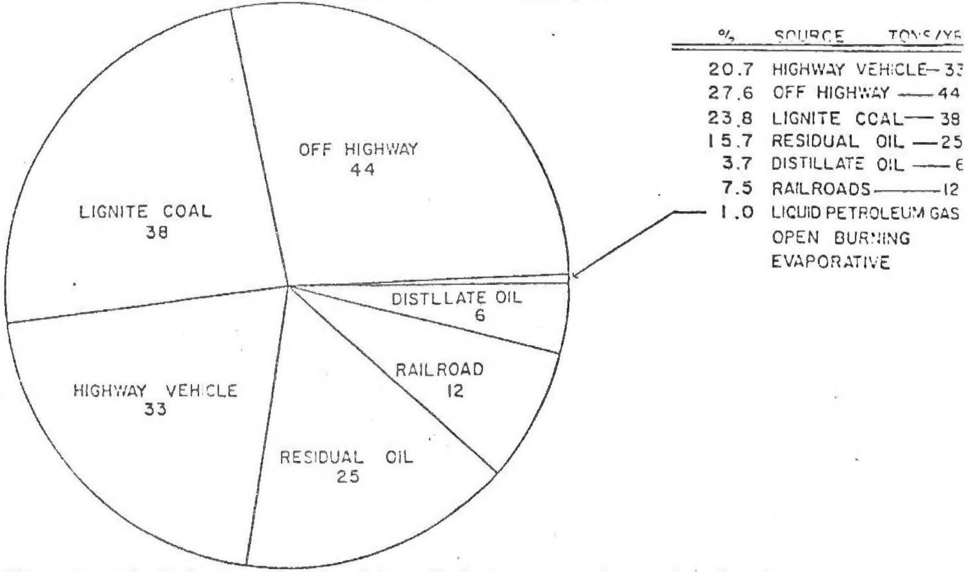


FIGURE 20

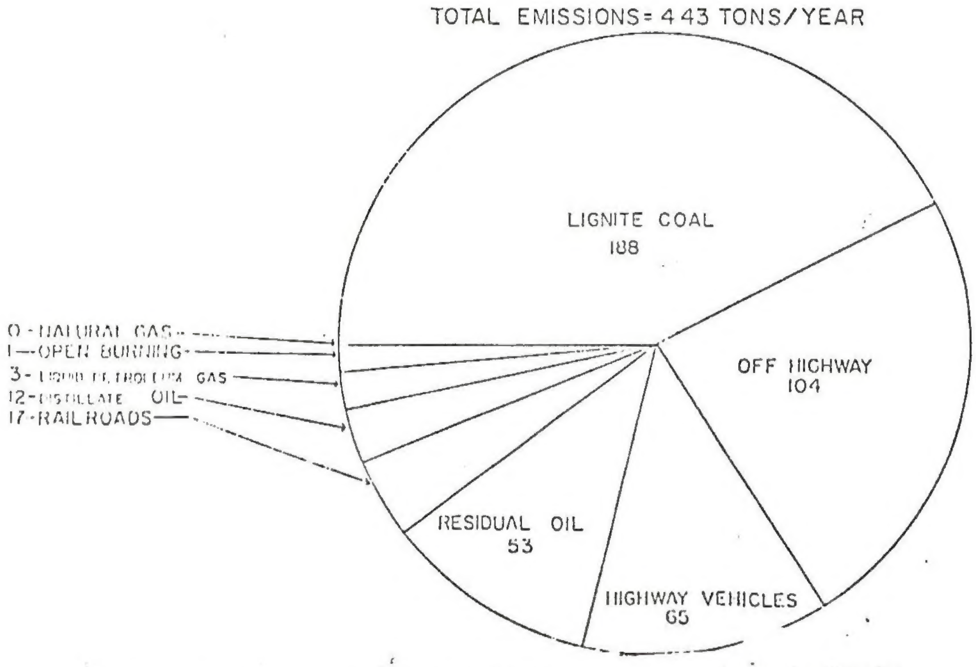
1975 AREA SOURCE SULFUR DIOXIDE EMISSIONS
McLEAN COUNTY
TOTAL EMISSIONS 159 Tons/yr.



SOURCE: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76 009 (1976)

FIGURE 21

1975 AREA SOURCE SULFUR DIOXIDE (SO_2) EMISSIONS FOR OLIVER, MERCER McLEAN AND DUNN COUNTIES WITHIN THE STUDY AREA



PER CENT BY SOURCE	
2.7	DISTILLATE OIL
11.9	RESIDUAL OIL
NEG 0.0	NATURAL GAS
3.8	RAILROADS
.2	OPEN BURNING
0.1	LIQUID PETROLEUM GAS
42.4	LIGNITE COAL
23.4	OFF HIGHWAY
14.6	HIGHWAY VEHICLES

Source: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

TABLE 20

MEASURED SULFUR DIOIXDE CONCENTRATION
ANNUAL ARITHMETIC MEAN

Site	Annual Arithmetic Mean Concentration 1975 ($\mu g/m^3$)1/	Annual North Dakota Ambient Air Quality Standard ($\mu g/m^3$)
Bismarck - Commercial	ND2/	60
Mott	7	60
Washburn	5	60
Beulah - Residential	10	60
Beulah - Rural	ND2/	60
Stanton	7	60

SOURCE: North Dakota State Department of Health 1976

NOTE : Bubbler Sampling Method Used

1/ Micrograms per cubic meter

2/ Sulfur dioxide not detected

TABLE 21

MEASURED SULFUR DIOXIDE CONCENTRATIONS MAXIMUM 24-HOUR CONCENTRATION

Site	Maximum 24-Hour Concentration, 1975 ($\mu g/m^3$) 1/	24-Hour North Dakota Ambient Air Quality Standards ($\mu g/m^3$)
Mott	41	260
Washburn	50	260
Beulah - Residential	54	260
Beulah - Rural	< 25 2/	260
Stanton	42	260
Bismarck - Commercial	< 25 2/	260

SOURCE: North Dakota State Department of Health 1976

NOTE : Bubbler Method Used

1/ Micrograms per cubic meter

2/ Sulfur dioxide values less than lowest detectable limit of 25 $\mu g/m^3$

TABLE 22

MEASURED SULFUR DIOXIDE CONCENTRATIONS HOURLY MAXIMUM VALUES FOR ANY GIVEN MONTH AT STANTON 1975

Month	Hourly Recorded Maximum 1975 ($\mu g/m^3$)1/	One-Hour North Dakota Ambient Air Quality Standard ($\mu g/m^3$)
January	131	715
February	131	715
March	<26.1 2/	715
April	26.1	715
May	26.1	715
June	78.4	715
July	52.4	715
August	26.1	715
September	52.4	715
October	26.1	715
November	<26.1 2/	715
December	26.1	715

SOURCE: North Dakota State Department of Health 1976

NOTE: Continuous Sampling Method

1/ Micrograms per cubic meter

2/ Values less than lower detectable limit of 26.1

three-hour value of 1300 μg/m^3 exists as a Federal Secondary Standard.

Oxides of nitrogen as NO_2 which was contributed to the ambient air in the study area for 1975 from area sources has been determined. Total emissions of NO_2 in tons per year and the percent contribution by each area source to this total for Oliver, Mercer, McLean and Dunn Counties is shown in Figures 22 through 25. Figure 26 is a composite of this data.

Ambient air concentrations of NO_2 have been measured at several locations in the seven county study area for the period of 1974-1976. The specific sampling locations include Bismarck, Mandan, Washburn, Stanton, Beulah, Mott, and Dickinson. The annual arithmetic mean concentrations in micrograms per cubic meter of air for each sampling station is shown in Table 23. The maximum hourly concentrations in micrograms per cubic meter of air recorded for each month during 1975 at those sites lying within the study area is presented in Table 24.

Current North Dakota Ambient Air Quality Standards establish a permissible ambient air concentration for NO_2 of 100 μg/m^3 as an annual arithmetic mean and a maximum one-hour concentration of 200 μg/m^3 not to be exceeded over one percent of the time in any three-month period. The Federal Ambient Air Quality Standard for pemissible ambient air concentrations of NO_2 is 100 μg/m^3 as an annual average. At the present time, there is

FIGURE 22

1975 AREA SOURCE OXIDES OF NITROGEN EMISSIONS
DUNN COUNTY

TOTAL EMISSIONS 567 tons/yr.

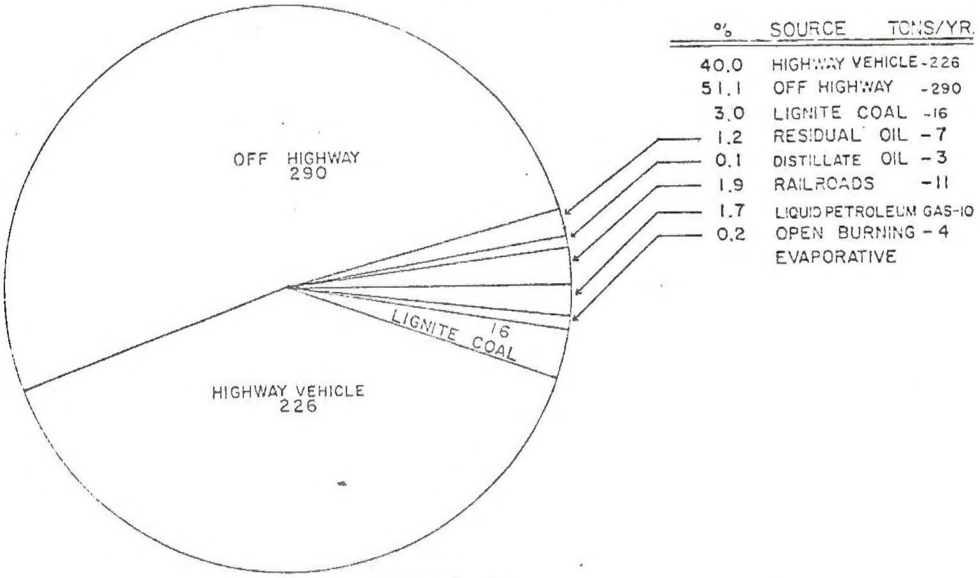
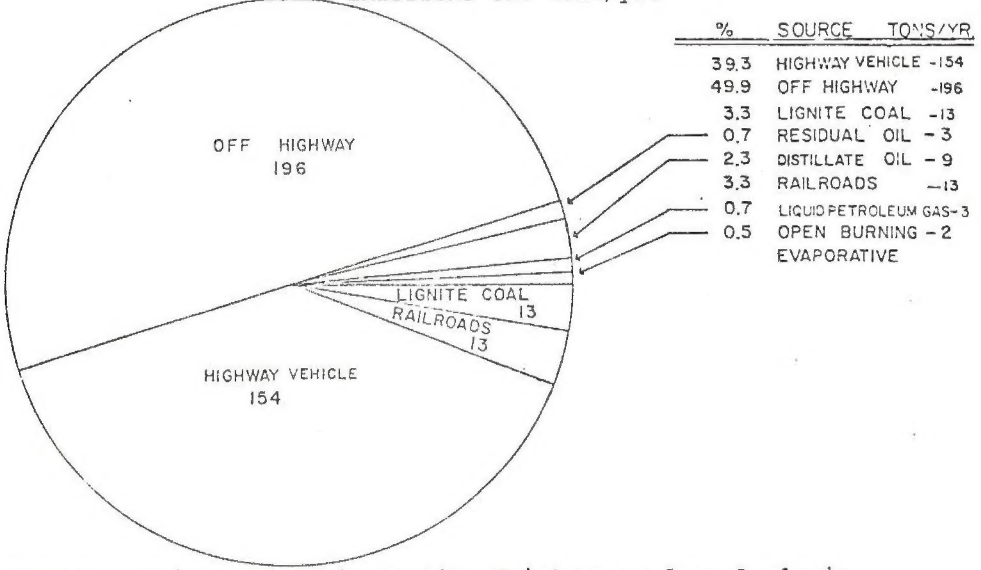


FIGURE 23

1975 AREA SOURCE OXIDES OF NITROGEN EMISSIONS
OLIVER COUNTY

TOTAL EMISSIONS 393 tons/yr.

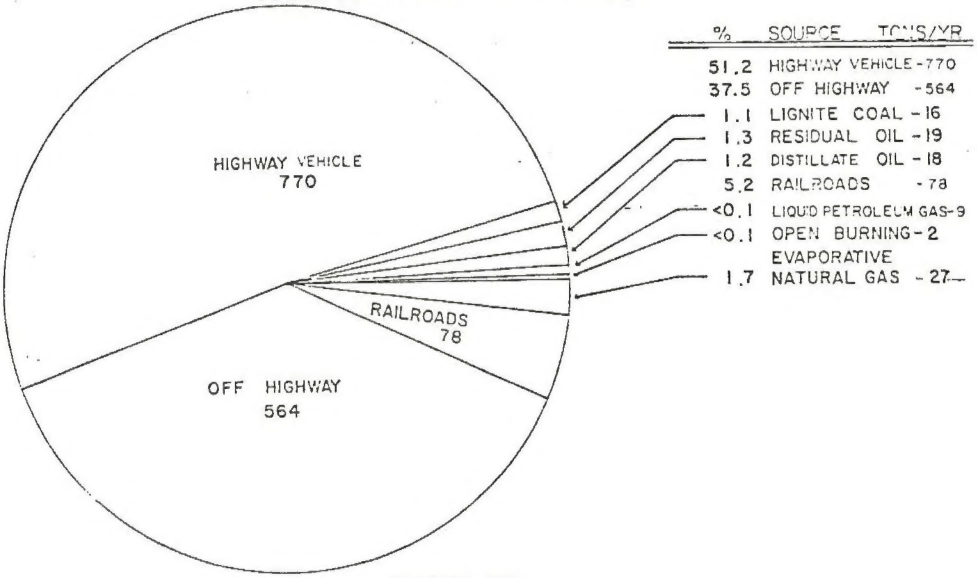


SOURCE: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

FIGURE 24

1975 AREA SOURCE OXIDES OF NITROGEN EMISSIONS
McLEAN COUNTY

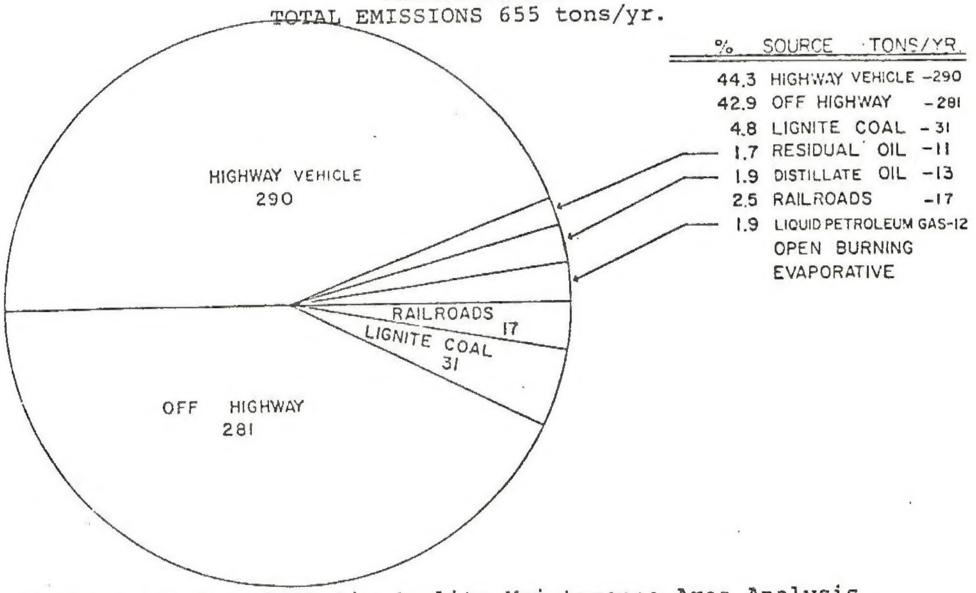
TOTAL EMISSIONS 1503 tons/yr.



%	SOURCE	TONS/YR.
51.2	HIGHWAY VEHICLE	-770
37.5	OFF HIGHWAY	-564
1.1	LIGNITE COAL	-16
1.3	RESIDUAL OIL	-19
1.2	DISTILLATE OIL	-18
5.2	RAILROADS	-78
<0.1	LIQUID PETROLEUM GAS	-9
<0.1	OPEN BURNING	-2
	EVAPORATIVE	
1.7	NATURAL GAS	-27

FIGURE 25

1975 AREA SOURCE OXIDES OF NITROGEN EMISSIONS
MERCER COUNTY
TOTAL EMISSIONS 655 tons/yr.

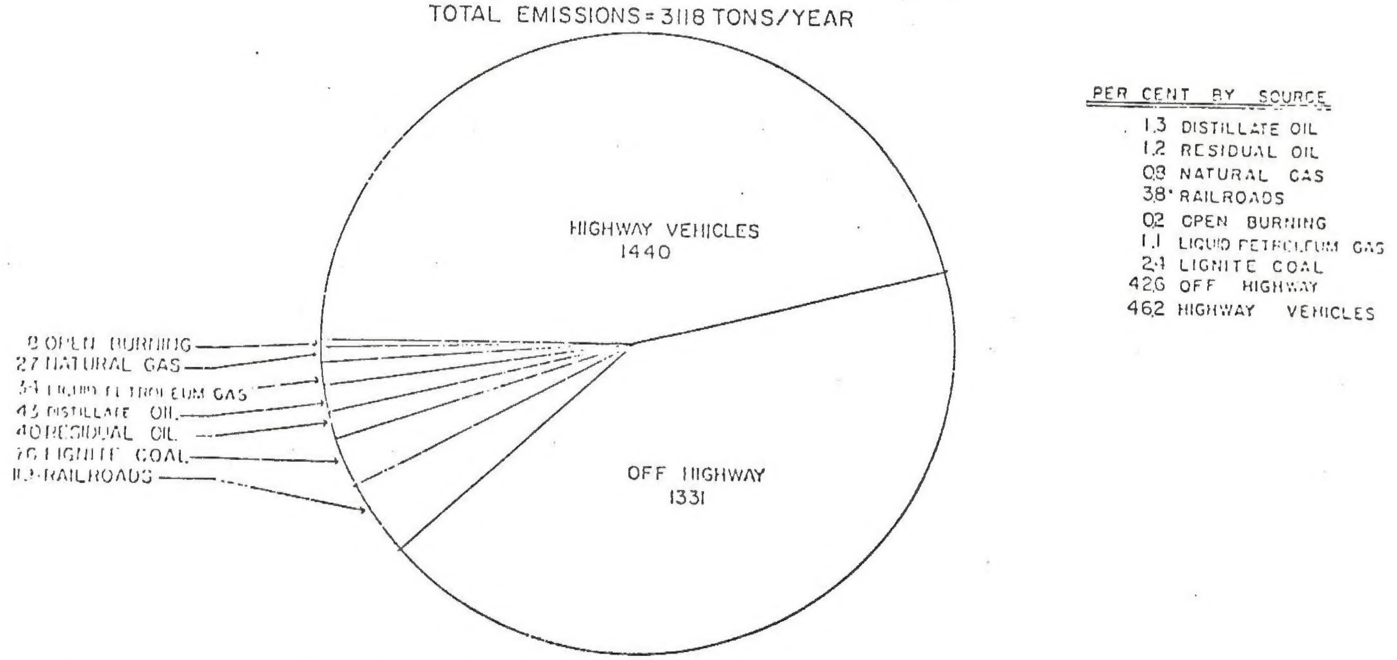


%	SOURCE	TONS/YR.
44.3	HIGHWAY VEHICLE	-290
42.9	OFF HIGHWAY	-281
4.8	LIGNITE COAL	-31
1.7	RESIDUAL OIL	-11
1.9	DISTILLATE OIL	-13
2.5	RAILROADS	-17
1.9	LIQUID PETROLEUM GAS	-12
	OPEN BURNING	
	EVAPORATIVE	

SOURCE: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

FIGURE 26

1975 AREA SOURCE NITROGEN DIOXIDE (NO_2) EMISSIONS FOR OLIVER, MERCER McLEAN AND DUNN COUNTIES WITHIN THE STUDY AREA



Source: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

TABLE 23

MEASURED NITROGEN DIOXIDE CONCENTRATIONS ANNUAL ARITHMETIC MEAN

Site	Arithmetic Mean Concentration 1975 (μg/m³) 1/	Annual North Dakota Ambient Air Quality Standard (μg/m³)
Bismarck - Commercial	20	100
Mott	8	100
Washburn	4	100
Mandan	28	100
Beulah - Residential	17	100
Beulah - Rural	10	100
Stanton	5	100

SOURCE: North Dakota State Department of Health 1976

NOTE: Bubbler Sampling Method

1/ Micrograms per cubic meter

TABLE 24

MEASURED NITROGEN DIOXIDE CONCENTRATIONS HOURLY MAXIMUM VALUES FOR ANY GIVEN MONTH

Month	Hourly Recorded Maximum 1975 (μg/m^3)1/	One-Hour North Dakota Ambient Air Quality Standard (μg/m^3)
January	38	200
February	56	200
March	38	200
April	38	200
May	56	200
June	19	200
July	19	200
August	<19 2/	200
September	56	200
October	38	200
November	56	200
December	19	200

SOURCE: North Dakota State Department of Health 1976

NOTE: Continuous Method

1/ Micrograms per cubic meter

2/ Value less than lower detectable limit of 19 no Federal Standard for maximum short-term allowable ambient air concentrations of NO_2. The ambient air concentration of NO_2 in the study area is within the allowable limits as set forth in both the State and Feceral Ambient Air Quality Standards.

Reactive sulfur (sulfation) is a measure of sulfur oxide compounds, primarily sulfur dioxide, sulfur trioxide, and sulfuric acid in the ambient air. Sulfur trioxide and sulfuric acid are thought to be primarily formed in the ambient air from sulfur dioxide emissions from energy conversion sources, although a small amount of sulfur trioxide and sulfuric acid is also emitted directly by various other types of point sources.

Ambient air concentrations of reactive sulfur as SO_3 have been measured at several locations throughout the study area. Table 25 presents the sample locations and minimum and maximum one-month recorded values of reactive sulfur as SO_3 for 1975 and 1976. North Dakota Ambient Air Quality Standards for reactive sulfur (sulfation) are 0.25 milligrams SO_3 per 100 square centimeters per day, maximum annual arithmetic mean, and 0.50 milligrams SO_3 per 100 square centimeters per day as the maximum for a one-month period. All values recorded in the study area are within the permissible concentration limits as established by the State Ambient Air Quality Standards.

Ambient air concentrations of hydrocarbons within the study area have not been extensively measured up to the present time.

TABLE 25

MEASURED REACTIVE SULFUR MINIMUM AND MAXIMUM CONCENTRATIONS FOR ANY GIVEN MONTH

Location of Sampling Site	Concentration (Min.)[2] (mg SO_3/100 cm^2/day)[1]	(Max.)	Maximum One-Month North Dakota Ambient Air Quality Standard (mg/SO_3/100 cm^2/day)
Bismarck - Commercial	<0.1	0.2	0.5
Bismarck - Industrial	<0.1	0.2	0.5
Mandan	<0.1	0.3	0.5
Stanton	<0.1	0.1	0.5
Beulah - Residential	<0.1	0.4	0.5
Beulah - Rural	<0.1	0.2	0.5
Garrison	<0.1	0.1	0.5
Dickinson - Commercial	<0.1	0.2	0.5
Washburn	<0.1	0.1	0.5

SOURCE: North Dakota State Department of Health 1976

1/ Values as milligrams sulfur trioxide per one hundred square centimeters per day (mg SO_3/100 cm^2/day)

2/ Value less than lower detectable limit of 0.1 milligrams SO_3/100 cm^2/day

Therefore, insufficient data exists to establish baseline ambient air levels in the rural environment of the study area. The primary sources of hydrocarbon emissions include motor vehicles, fuel combustion, industrial processes, and solid refuse disposal by burning. Of these sources nationally, motor vehicles contribute 70 percent of all hydrocarbon emissions to the ambient air. Combustion of all types of fuels contribute on the average approximately 3 percent, and all industrial sources in general contribute approximately 2 percent.

Reactions of hydrocarbons in the atmosphere are important primarily because they give rise to secondary contaminants and reaction intermediates that cause nearly all of the detrimental effects of hydrocarbon air contamination. The chemistry of these reactions and their products is not fully known. It is known, however, that hydrocarbons become involved in the photochemical air contaminant complex because of their reactions with oxygen atoms, ozone molecules, and free radicals generated by the action of sunlight on other components in the atmosphere.

Carbon monoxide, as with hydrocarbons, has not been extensively measured throughout the seven county study area. Because of the lack of data, it has not been possible to establish an existing background concentration for carbon monoxide in the study area environment. In studies on carbon monoxide concentrations in relatively unpolluted air, it has been estimated that an expected background level in the lower atmosphere is approximately 0.01 to 0.2 milligrams per cubic meter (0.01 to 0.02 ppm).

The largest single source of carbon monoxide is the exhaust of motor vehicles, both gasoline and diesel-powered. These exhaust emissions account for approximately 63 percent of all carbon monoxide emissions to the ambient air. Other sources include stationary combustion, industrial-related processes involving coal, fuel oil, natural gas, and wood. These combustion sources contribute approximately 2 percent of the total ambient air emissions of carbon monoxide annually.

No projections can be made concerning the potential increases in carbon monoxide emissions to the ambient air from stationary industrial sources due to a lack of existing data. It would be expected, that as industrial development expands within the study area, carbon monoxide emissions and resulting ambient air concentrations will increase. However, it must be recognized that changes in industrial processes and the application of more effective control technology along with newer methods of solid waste disposal may result in decreases in the carbon monoxide emissions to the ambient air. With the application of control technology, it is not expected that the ambient air concentrations of carbon monoxide within the study area will exceed the existing State and Federal ambient air standards.

Photochemical oxidants are another group of compounds which are expected to be found in increased concentrations in the ambient air of the study area as a result of the proposed energy development. Oxidants themselves, are not emitted directly into the atmosphere, but are produced by a series of chemical reactions between organic compounds, including hydrocarbons and nitrogen oxides, in the presence of sunlight. Research has shown that the rate of oxidant formation is affected by the specific organic compounds present, the ratio of organic compounds to nitrogen oxides, and meteorological conditions such as solar intensity, temperature, and atmospheric stability.

Generally, peak concentrations of photochemical oxidants are measured within a few hours of noon, although the emissions of precursor compounds (organics and nitrogen oxides) contributing to these peak concentrations may occur several hours earlier or remain from the previous day. Since the atmospheric photochemical reactions usually take several hours, the measured oxidant concentrations may occur many miles downwind from the points of emission origin.

The probable sources of oxidants in the study area and most other rural locations are downward transport from the ozone-rich layers of the stratosphere due to strong vertical mixing and the photochemical generation from organics emitted by vegetation. These natural sources of photochemical oxidants along with the secondary formation of oxidants from hydrocarbon and nitrogen oxide emissions are expected to constitute the primary sources of oxidants within the study area.

Research has shown that organic compounds emitted by vegetation may increase oxidants by as much as 40 to 100 micrograms per cubic meter ($\mu g/m^3$). Normally, atmospheric conditions which would produce high concentrations from downward mixing from the upper atmosphere are not conducive to high oxidant generation rates from vegetation and vice versa. However, the additive effect from these two sources gives values that support the hypothesis that measured concentrations of 160 $\mu g/m^3$ and higher in rural areas in the Great Plains are almost entirely due to natural sources of oxidants. (PEDCo Environmental, Inc. 1976)

Hydrogen sulfide (H_2S) also has not been extensively measured throughout the seven county area. Because of the lack of existing data, ambient air background concentrations of H_2S have not been established. There are presently no major industrial sources of H_2S in the study area. However, the potential for localized high H_2S ambient air concentrations as a result of "sour gas" from petroleum and natural gas production in western Dunn County is being evaluated by the NDSDH.

The only potential source of hydrogen sulfide emissions to the study area from industrial origin would appear to be lignite coal gasification plants. H_2S is expected to be emitted from these plants in small concentrations throughout their operational lifetimes.

A review of the preliminary designs of proposed gasification facilities indicates that the plants will be equipped with commercial sulfur recovery units which are expected to remove approximately 98 percent of the sulfur (primarily hydrogen sulfide) from the plant effluent gases. In addition to the sulfur recovery process, a portion of the remaining hydrogen sulfide in the effluent streams is oxidized by incineration to sulfur dioxide. The efficiency of these two processes does not remove all of the hydrogen sulfide in the various effluent streams. However, the remaining hydrogen sulfide within the stack gases reaching the ambient air is expected to be insignificant with increased ambient air concentrations of hydrogen sulfide being negligible.

Acid Rain

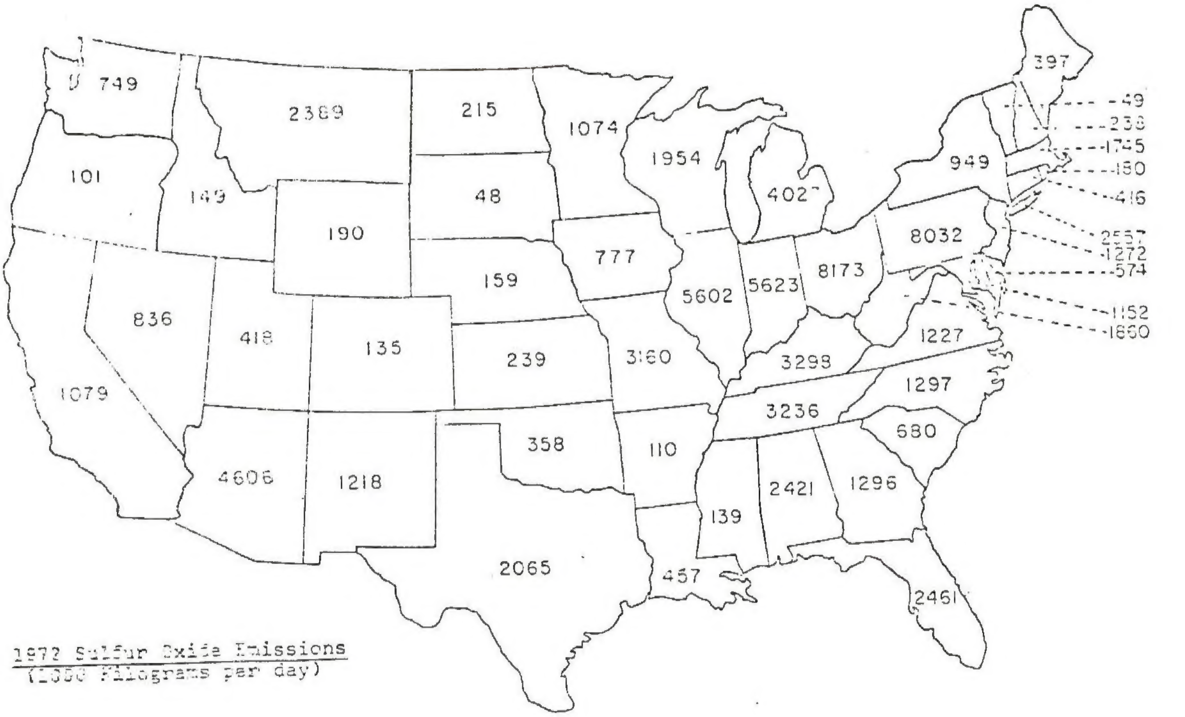
In recognition of increasing lignite coal development in western North Dakota, the State Department of Health has reviewed the experience of other states and nations in terms of deleterious environmental impacts resulting from industrial development. This entailed examination involved case histories of after-the-fact problems; problems which were either not expected or which resulted from inadequate control of emissions.

Problems experienced with acid rain have been reported from northwestern Europe (Oden, S., 1976; Overrein, L., 1976; Nordo, J., 1976; Ottar, B., 1976; Semb, A., 1976; and Klackow, D. and H. Denzinger, 1976), northeastern United States (Jacobson, J. et al., 1976; Boyce, S. and S. Butcher, 1976; Cogbill, C., 1976; Likens, G.E., and F.H. Bormann, 1974; and Likens, G.E. et al., 1972), and Canada (Hutchinson, T.C., 1976; Nyborg, M. and J. Crepin, 1976; and Baker, J. et al., 1976). In North Dakota, the only recorded corrosive atmosphere problems occurred during the 1960's in the oil and sour gas production areas of the northwestern corner of the State. Farm machinery and metal farm buildings were apparently damaged by sulfurous gases in combination with water vapor. These problems occurred prior to an Air Pollution Control Law in North Dakota, and industry voluntarily corrected them.

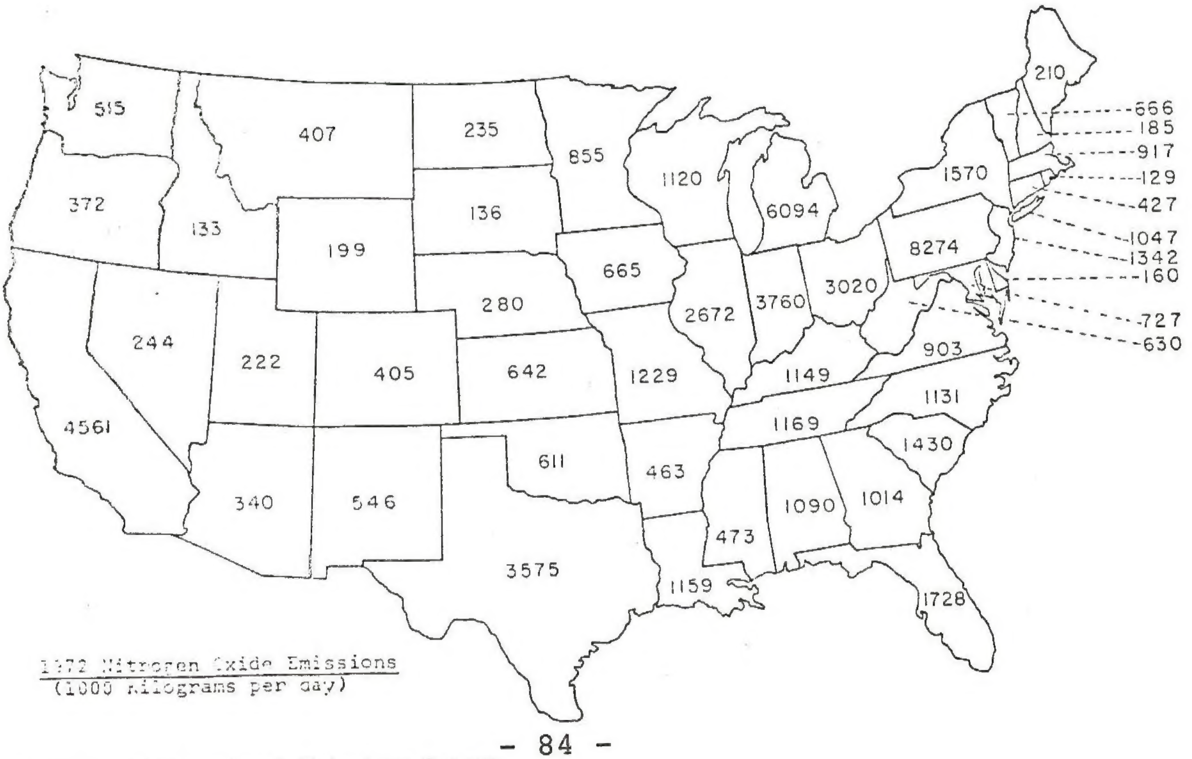
The potential for the problems in northeastern United States are evident by examination of Figure 27. This figure presents a geographic picture of the emissions of oxides of sulfur and nitrogen, by state, for 1972 (the last year that the Department could obtain national data). In addition to the density of these emissions in this section of the country, it was reported by Hutchinson 1976, that the annual emissions of SO_2 from smelters in the Sudbury, Ontario area of Canada were in excess of three million short tons in 1972.

NATIONWIDE EMISSIONS OF SULFUR AND NITROGEN--1972
(metric tons per day)

FIGURE 27



1972 Sulfur Oxide Emissions
(1000 kilograms per day)



1972 Nitrogen Oxide Emissions
(1000 kilograms per day)

Source: 1972 National Emissions Report
U.S. Environmental Protection Agency
EPA-450/2-74-012 (June 1974)

Even with the known energy development projects proposed for operation within North Dakota in the early 1980's, the total state-wide emissions of oxides of sulfur and nitrogen are not expected to exceed one half of the 1972 emissions reported for our neighboring state to the west, Montana. It would appear that the potential for an adverse, or episodic acid rain problem is low in North Dakota. However, one cannot entirely rule out localized problems developing in areas of more intensive energy development or under stable atmospheric conditions. It is important, in view of North Dakota's agricultural economy, to protect the rural environment from adverse atmospheric acidity. It is only through a properly functioning network of precipitation sampling stations for pH determinations that this protection will be insured. At the present time, only limited atmospheric pH data has been obtained by the North Dakota State Department of Health. Table 26 presents the available raw data obtained during 1977 at seven locations in western North Dakota.

Table 27 presents a statistical analysis of site specific rain data collected by the North Dakota State Department of Health. The time range over which the data was collected, the summation of samples, and the maximum and minimum pH values are presented in the table. In addition, the mean and the standard deviation are given.

The results of the pH data given in Table 27 indicate an all site pH average of 6.0 with individual site averages being

TABLE 26
ACID PRECIPITATION EVENTS AT SEVEN COLLECTION SITES IN WESTERN NORTH DAKOTA, 1977

Collection Location	Date Collected	pH
Bismarck	3-30-77	6.6
	5-3-77	7.2
	5-4-77	6.3
	5-16-77	6.6
	5-17-77	6.2
	5-23-77	6.2
	5-25-77	8.2
	5-27-77	7.0
	5-29-77	6.7
	5-31-77	6.2
	6-3-77	5.9
	6-9-77	7.0
	6-13-77	5.5
	6-14-77	5.4
	6-17-77	5.4
	6-21-77	6.0
	6-21-77	4.7,4.5,4.4
	6-22-77	5.8
	----	6.7
	7-5-77	5.8
	7-7-77	5.9
	7-11-77	5.2
	7-27-77	6.4
	8-5-77	5.4
	8-15-77	6.1
	8-25-77	6.2
	8-27-77	5.8
	8-30-77	5.7
	9-1-77	5.9
	9-7-77	6.3
	9-8-77	5.4
	9-8-77	6.2
	9-20-77	5.7
	9-22-77	6.4
	9-23-77	5.6
	9-24-77	6.2
	9-30-77	6.1
West of Mandan	5-4-77	6.3
	5-17-77	5.6
	5-25-77	5.8
	5-29-77	6.5
	5-29-77	6.4
	6-3-77	5.7
	6-11-77	5.1
	6-14-77	4.6
	7-11-77	6.1
	8-27-77	5.3
	8-31-77	6.2
	9-2-77	5.5
	9-17-77	6.1
	9-24-77	5.8
New England	8-22-77	5.7
	8-23-77	5.6
	8-26-77	5.6
	8-30-77	5.4
	8-31-77	5.9
	9-1-77	6.4
	9-18-77	6.3
	9-20-77	6.4
	9-23-77	6.1
	9-29-77	5.3
	9-30-77	5.6
	10-1-77	5.6
Halliday	7-16-77	5.2
	8-15-77	6.4
	8-23-77	5.3
	8-26-77	6.2
	8-29-77	7.8
	8-31-77	5.7
	9-2-77	5.3
	9-9-77	6.6
	9-19-77	6.8
	9-22-77	5.6
	9-24-77	4.9
	9-30-77	5.7
Lake Tschida	9-18-77	5.6
	9-22-77	6.0
	9-24-77	6.5
	9-30-77	5.9
	10-1-77	6.4
Grassy Butte	5-18-77	6.3
	8-28-77	6.6
	9-21-77	5.8
	9-30-77	6.1
Mandaree	7-17-77	6.5
	7-28-77	5.9
	8-5-77	6.1
	8-29-77	6.0

SOURCE: North Dakota State Department of Health 1977

TABLE 27

RAINFALL pH ANALYSIS BY SITE LOCATION (1977)

Site Location	Date Range	pH
Bismarck	3-30/9-30	
Total (Σ)		234.8
Max (X_{max})		8.2
Min (X_{min})		4.4
Mean ($\overline{X}$)		6.0
No. of Samples (n)		39
Standard Deviation (σ)		0.73
Grassy Butte	5-18/9-30	
Total (Σ)		24.8
Max (X_{max})		6.6
Min (X_{min})		5.8
Mean ($\overline{X}$)		6.2
No. of Samples (n)		4
Standard Deviation (σ)		0.34
Mandaree	7-17/9-30	
Total (Σ)		24.5
Max (X_{max})		6.5
Min (X_{min})		5.9
Mean ($\overline{X}$)		6.1
No. of Samples (n)		4
Standard Deviation (σ)		0.26
Halliday	7-17/9-30	
Total (Σ)		71.5
Max (X_{max})		7.8
Min (X_{min})		5.2
Mean ($\overline{X}$)		6.0
No. of Samples (n)		12
Standard Deviation (σ)		0.83
New England	8-23/10-1	
Total (Σ)		69.9
Max (X_{max})		6.4
Min (X_{min})		5.3
Mean ($\overline{X}$)		5.8
No. of Samples (n)		12
Standard Deviation (σ)		0.39
Mandan	6-21/9-24	
Total (Σ)		86.4
Max (X_{max})		6.5
Min (X_{min})		4.6
Mean ($\overline{X}$)		5.8
No. of Samples (n)		15
Standard Deviation (σ)		0.53
Lake Tschida	9-18/10-1	
Total (Σ)		30.4
Max (X_{max})		6.5
Min (X_{min})		5.6
Mean ($\overline{X}$)		6.1
No. of Samples (n)		5
Standard Deviation (σ)		0.37

SOURCE: North Dakota State Department of Health 1977

within ± 0.2 pH units of this average value. The maximum pH reading measured was 8.2, the minimum pH reading was 4.4; both collected at the Bismarck site. This probably occurred because the site had the highest number of precipitation events measured. The data presented here can only be used as an indication of rain acidity. Much more data which is collected over a longer period of time is needed.

Normal atmospheric moisture in equilibrium with atmospheric carbon dioxide will have a pH of 5.7 (Barrett, E., and G. Brodin, 1975). Assuming this pH value to be neutral, then the average pH value measured should be considered slightly alkaline at all site locations. The data agrees with studies of pH of atmospheric rainfall in Iowa (Tabatabai, M.A., and J.M. Laflen, 1976) and a low population, low industrial development area of Michigan's upper peninsula (Richardson, C.J., and G.E. Merva, 1976; Semonin, R.G., 1976).

PROJECTED AMBIENT AIR QUALITY EFFECTS OF PROPOSED ENERGY DEVELOPMENT

Meteorology of the Study Area

The capacity of the atmosphere to effectively disperse and dilute contaminants injected into it is primarily determined by the horizontal and vertical behavior of its properties, most important of which are temperature and wind. The horizontal distribution of air temperature is normally observed at all Cooperative Weather Bureau stations. However, long-term records of vertical profiles of temperature, as well as wind observations are available only from sparsely-spaced National Weather Service stations. Table 28 presents the maximum observed wind speeds and their associated directions from long-term wind records at Williston and Bismarck.

In the absence of any other source of longer-term records of wind and vertical air temperature profiles, other techniques can be used to describe, in a general way, the atmospheric dispersion capability of the proposed site area. The work of Holzworth (1972) provides a general assessment of the atmospheric stability from available long-term data records. His estimates of mean morning and afternoon mixing heights in the general study area are outlined in Table 29. Holzworth also calculated the average wind speed through the mixing layer (Table 29).

TABLE 28

MAXIMUM OBSERVED WIND SPEEDS AND ASSOCIATED DIRECTIONS AT NEARBY STATIONS

	Station	J	F	M	A	M	J	J	A	S	O	N	D	ANN
Maximum Observed Wind Speed (mph)	Williston	70	66	52	56	56	61	64	47	50	57	47	56	70
Associated Wind Direction		NW	NW	NW	SW	NW	NW	NW	W	NW	N	NW	W	NW
Peak Gust (mph)		91	86	68	73	73	80	83	61	65	74	61	73	91
Maximum Observed Wind Speed (mph)	Bismarck	54	59	65	63	66	66	72	72	66	61	67	61	72
Associated Wind Direction		NW	NW	NW	W	NW	N	W	S	NW	W	NW	NW	W
Peak Gust (mph)		70	77	85	82	86	86	94	94	86	79	87	79	94

SOURCE: U.S. Department of Commerce, 1973a, b; Thom, H.C.S., 1968

TABLE 29

ESTIMATED MEAN MIXING HEIGHTS (METERS) AND MEAN MIXING LAYER WIND SPEEDS (METERS PER SECOND) AT THE SITE AREA

	ANNUAL	WINTER	SPRING	SUMMER	FALL
Morning					
Mean Mixing Height	300-400	300-400	400-500	300	300
Mean Wind Speed	3.0-3.5	3.0-3.5	4.0-4.5	3.0	3.0
Afternoon					
Mean Mixing Height	1500-1600	600-800	1800-2200	2000-2800	1200-1600
Mean Wind Speed	14.0-16.0	6.0-7.0	18.0-20.0	20.0-24.0	13.0-14.0

SOURCE: Holzworth, G.C., 1972

The mean mixing heights in the vicinity of the proposed projects are generally less in the mornings than in the afternoons and Holzworth's data indicates greater afternoon mixing heights during spring and summer than during the other seasons of the year. Likewise afternoon wind speeds are generally greater than morning wind speeds averaging about 3.0 meters per second.

The combination of shallow mixing heights and low wind speeds will tend to inhibit dispersion of air contaminants and conversely, higher mixing heights and wind speeds tend to enhance dispersion. According to the National Air Pollution Potential Forecasting Program (Stackpole, 1967; Bross, 1970) the dispersion of contaminants is limited when mixing heights are 1,500 meters or less and mixing layer wind speeds are 4 meters per second or less. Holzworth (1972) tabulated the number of cases of such restrictive condtions for the five-year period, 1960-1964. Episodes persisting for at least two days for various combination of mixing heights and wind speeds are summarized based upon Bismarck, North Dakota data in Table 30.

Eight episodes of 1,500 meters or less mixing height and a 4 meter per second or less wind speed were observed in the five-year period and persisted for a total of 19 days. The greatest frequency of episodes occurred in the winter months.

A method for determining and classifying atmospheric stability from long-term surface meteorological observations utilizing the

TABLE 30

NUMBER OF RESTRICTED MIXING EPISODES LASTING TWO OR MORE DAYS IN FIVE YEARS AND TOTAL EPISODE DAYS (IN PARENTHESIS) IN BISMARCK, NORTH DAKOTA

WIND SPEED	MIXING HEIGHTS		
	< 500 m	< 1000 m	< 1500 m
≤ 2.0 m/sec	0(0)	0(0)	0(0)
≤ 4.0 m/sec	5(12)	6(15)	8(19)
≤ 6.0 m/sec	13(39)	20(56)	29(77)

SOURCE: Holzworth, G.C., 1972

parameters of sky cover, wind speed and solar angle (time of day) was used for evaluating regional conditions. This method, developed by Pasquill (1961) and improved by Turner (1964), states that unstable conditions occur when the atmosphere near the surface undergoes warming during instances of low wind speeds, and stable conditions occur with atmospheric cooling associated with low wind speeds. Neutral conditions occur with either cloudy skies or high wind speeds. Generally, unstable and neutral conditions favor the rapid dispersion of emissions and stable conditions are associated with poor dispersion.

The Pasquill/Turner stability classifications and the corresponding Nuclear Regulatory Commission (1972) vertical temperature classifications which most closely correlate to this method are presented in Table 31. The Pasquill/Turner stability classification scheme, consisting of joint wind speed/wind direction relative frequency distributions by stability class (STAR Program), has been compiled for the first-order National Weather Service station at Bismarck.

The atmospheric diffusion characteristics of the region have been estimated from the frequency and duration of the stagnating high pressure systems affecting the area. Such systems limit the dispersion of effluents, and those systems which remain stationary for several days may tend to cause a buildup of pollutants. Korshover (1971) studied cases of stagnating high pressure systems which persisted four days or more during a 30-

TABLE 31

STABILITY CLASSIFICATIONS

Pasquill/Turner Classification	Atmospheric Stability	Temperature Gradient (DT/DZ (°C/100m)
A	Very unstable	<-1.90
B	Unstable	-1.70 to -1.90
C	Slightly unstable	-1.50 to -1.69
D	Neutral	-0.5 to -1.49
E	Stable	1.5 to -0.49
F	Very stable	>1.5

SOURCE: Nuclear Regulatory Commission (1972) year period (1936-1965); no cases in west central North Dakota were identified.

Inversions, increases in temperature with height, generally tend to restrict vertical and horizontal dispersion of pollutants. Bismarck is the nearest location within the seven county study area where long-term vertical temperature profile data is available. From five years (1960-1964) of Bismarck 1200 GMT (Greenwich mean time) upper air data, the frequency of occurrence of inversions based from the surface to 100 meters and having a thickness of at least 250 meters is presented in Table 32. Although strong low-level inversions occurred nearly half the time in the early morning (0600 local time), accompanying low wind speeds (0-5 mph) were present for less than 4% during inversion observations.

Diffusion Models

The dispersion analysis used to evaluate the impact on the air quality resulting from the operation of the existing and proposed facilities was based on techniques and methods developed by the United States Environmental Protection Agency (EPA) as published in the Workbook of Atmospheric Dispersion Estimates, (Turner, 1970).

This analysis utilized the EPA's Users' Network for Applied Modeling of Air Pollution (UNAMAP) dispersion modeling package

TABLE 32

PERCENT FREQUENCY OF INVERSION BASED NEAR THE SURFACE FOR BISMARCK,[1] 1960-1964

Time Period	Inversion[2] % Occurrence	Wind Speed[3] 0.5 mph (%)
Dec. - Feb.	47.6	3.0
Mar. - May	38.2	2.7
June - Aug.	57.9	4.3
Sept.- Nov.	57.5	2.9
Annual	49.3	3.6

SOURCE: Inversion Study for Bismarck, National Climatic Center

[1] 1200 GMT Radiosonde Data
[2] Inversion Base from Surface - 100m and Thickness ≥ 250m
[3] Wind Speed at 300m

which is the property of the North Dakota State Department of Health (NDSDH) and is installed at the State of North Dakota's Central Data Processing (CDP) computer center located at the State Highway Building in Bismarck. The UNAMAP package consists of six separate subroutines. This analysis utilized three of these subroutines which allow dispersion estimates to be calculated consistent with the NDSDH air pollution standards. The subroutines are the PTMAX and PTMTP for short-term analysis and the Climatological Dispersion Model (CDM) for long-term analysis. Briggs plume rise equations are used in all the UNAMAP programs.

Short-term Diffusion Modeling

The PTMAX estimates ground level concentration (GLC) from a single point source. It predicts the maximum GLC, the distance from the source this maximum occurs, and under what meteorological conditions would induce this maximum GLC, e.g., wind speed and stability class. PTMTP estimates GLC from multiple point sources. This subroutine allows the estimation of GLC at a number of different receptors and allows specific meteorology conditions to be analyzed. Several conditions and assumptions are necessary when these models are utilized. These are:

1. Plant operates under steady state conditions.
2. Limited contaminant deterioration through the averaging time interval.

3. Meteorological conditions remain constant through averaging time interval.

4. Gaussian type (normal) dispersion of contaminants.

5. The model predicts GLC with reasonable realistic accuracy for ten minute averaging times. Emperical studies in the northern Great Plains have shown that each stability class reflects its own averaging time. See below:

   Stability Class A & B = 10 minute averages
   Stability Class C = 1 hour averages
   Stability Class D = 3 hour averages
   Stability Class E & F = 10 minutes to 1 hour averages

6. A conversion of the models' estimates to averaging times consistent with the State standard averaging times is necessary. The following method was used:

$$\chi_2 = \chi_1 \left(\frac{t_2}{t_1}\right)^{-B}$$

Where χ_1 = Concentrations predicted by the model
χ_2 = Adjusted concentration
t_1 = Averaging time for specific stability class (see table in Number 5. above.)
t_2 = Desired average time compatible with State Standard, i.e., 1-hour, 3-hour, 24-hour.
B = Constant of 0.44

This conversion should only be used up to 24-hour average time intervals.

Example: $\chi_1 = 250\ \mu g/m^3$

t_1 = 10 minute average (A Stability)

Find concentration (χ_2) for 24-hour time period.

Therefore:

$$\chi_2 = \chi_1 \left(\frac{t_2}{t_1}\right)^{-B}$$

$$\chi_2 = 250\ \mu g/m^3 \quad \left(\frac{24 \text{ hour x } 60 \text{ min/hr}}{10 \text{ minutes}}\right)^{-0.44}$$

$$\chi_2 = 250\ \mu g/m^3 \quad (.11)$$

Thus a factor of 0.11 is multiplied by the models prediction (χ_1) giving a predicted concentration of 27.50 $\mu g/m^3$ for a 24-hour period.

Table 33 presents factors for all stability classes and all relevant time averaging periods (t_2), using the above equation.

The meteorology source for the short-term modeling was obtained from the Climatic Data Laboratory at North Dakota State University (NDSU) in a document entitled "An Air Pollution Climatology of a Seven-County Area in Western North Dakota", Ramirez and Method, 1976. The stability class/wind rose calculations were obtained from analysis of Bismarck weather station records for a 27-year period (1948-1974). This data is summarized in Table 34.

The following equations are used for calculation of short-term concentrations:

Plume Rise

Neutral and Unstable $\Delta h = \frac{1.6}{U} F^{1/3} (3.5\, X^{*})^{2/3}, \quad X^{*} = 34.F^{2/5}$ eq. 1

Stable $\Delta h = 2.4 \left(\frac{F}{US}\right)^{1/3}$

Normal Dispersion

$$\chi = \frac{Q}{\pi U \sigma_y \sigma_z} \exp -1/2(H/\sigma_z)^2 \qquad \text{eq. 2}$$

Limited Mixing Dispersion

$$\max \chi = \frac{Q}{(2\pi)^{1/2} \sigma_y UL} \text{ at distance } \chi \qquad \text{eq. 3}$$

χ is twice the distance where $\sigma_z = .47L$

Inversion Breakup Dispersion

$$\max \chi = \frac{Q}{(2\pi)^{1/2}(\sigma_y + \frac{H}{8})(2\sigma_z + H)U} \text{ at distance } \chi \qquad \text{eq.4}$$

$$\chi = Ut_m, t_m = \frac{\rho C_p}{R} \frac{d\theta}{dz} (\Delta h + 2\sigma_z)(h + \frac{\Delta h}{2} + \sigma_z)$$

Where:

C_p - Specific heat at constant pressure {cal/g/°K}

F - Momentum flux, $= gvr^2 \frac{(p-p_s)}{p}$, $\{m^4/sec^3\}$

g - Acceleration of gravity $\{m/sec^2\}$

h - Stack Height {m}

Δh - Plume rise {m}

H - Effective stack height, $= h + \Delta h$, {m}

L - Mixing depth {m}

Q - Effluent emission rate {g/sec}

R - Net rate of sensible heating of an air column by solar radiation $\{cal/m^2/sec)$

s - Restoring acceleration per unit vertical displacement for adiabatic motion, $= g/T \frac{d\theta}{dz}$, $\{sec^{-2}\}$

t - Averaging time interval {sec}

t_m - Time required to heat stable column of air between stack top and plume top {sec}

U - Wind speed {m/sec}

v - Effluent exit velocity {m/sec}

X - Longitudinal plume distance {m}

$\frac{d\theta}{dz}$ - Vertical potential temperature gradient {°K/m}

p - Ambient air density $\{g/m^3\}$

p_s - Exit gas density $\{g/m^3\}$

σ_y - Horizontal dispersion coefficient {m}

σ_z - Vertical dispersion coefficient {m}

χ - Ground-level effluent concentration $\{g/m^3\}$

TABLE 33

CORRECTION FACTORS FOR t_2

Stability Classes	t_1 Assumed Time Period	1-Hour	3-Hour	24-Hour
A & B	10 minute	0.45	0.28	0.11
C	1 hour	1.0	0.61	0.24
D	3 hour	1.62	1.0	0.4
E & F	1 hour	0.73	0.45	0.18

TABLE 34

PERCENT FREQUENCIES OF WIND SPEED/WIND DIRECTION COMBINATIONS
FOR EACH STABILITY CLASS IN BISMARCK (1948 - 1974)

Stability Class	Direction	Wind Speed (Knots) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	>21	Total
A	N	0.000056	0.000034	0.000000	0.000000	0.000000	0.000000	0.000090
A	NNE	0.000051	0.000095	0.000000	0.000000	0.000000	0.000000	0.000146
A	NE	0.000067	0.000051	0.000000	0.000000	0.000000	0.000000	0.000118
A	ENE	0.000107	0.000095	0.000000	0.000000	0.000000	0.000000	0.000202
A	E	0.000129	0.000084	0.000000	0.000000	0.000000	0.000000	0.000213
A	ESE	0.000090	0.000073	0.000000	0.000000	0.000000	0.000000	0.000163
A	SE	0.000090	0.000135	0.000000	0.000000	0.000000	0.000000	0.000225
A	SSE	0.000073	0.000112	0.000000	0.000000	0.000000	0.000000	0.000185
A	S	0.000095	0.000112	0.000000	0.000000	0.000000	0.000000	0.000208
A	SSW	0.000079	0.000067	0.000000	0.000000	0.000000	0.000000	0.000146
A	SW	0.000152	0.000101	0.000000	0.000000	0.000000	0.000000	0.000253
A	WSW	0.000135	0.000124	0.000000	0.000000	0.000000	0.000000	0.000258
A	W	0.000163	0.000107	0.000000	0.000000	0.000000	0.000000	0.000270
A	WNW	0.000157	0.000135	0.000000	0.000000	0.000000	0.000000	0.000292
A	NW	0.000101	0.000051	0.000000	0.000000	0.000000	0.000000	0.000152
A	NNW	0.000045	0.000056	0.000000	0.000000	0.000000	0.000000	0.000101
B	N	0.000567	0.000561	0.000281	0.000000	0.000000	0.000000	0.001409
B	NNE	0.000376	0.000371	0.000185	0.000000	0.000000	0.000000	0.000932
B	NE	0.000657	0.000421	0.000219	0.000000	0.000000	0.000000	0.001297
B	ENE	0.001263	0.000601	0.000264	0.000000	0.000000	0.000000	0.002128
B	E	0.001465	0.000573	0.000320	0.000000	0.000000	0.000000	0.002358
B	ESE	0.001252	0.000792	0.000590	0.000000	0.000000	0.000000	0.002633
B	SE	0.001168	0.000736	0.000539	0.000000	0.000000	0.000000	0.002442
B	SSE	0.000938	0.000904	0.000668	0.000000	0.000000	0.000000	0.002510
B	S	0.000848	0.001162	0.000792	0.000000	0.000000	0.000000	0.002802
B	SSW	0.000999	0.001022	0.000775	0.000000	0.000000	0.000000	0.002796
B	SW	0.001039	0.001005	0.000472	0.000000	0.000000	0.000000	0.002515
B	WSW	0.001308	0.001252	0.000556	0.000000	0.000000	0.000000	0.003116
B	W	0.001752	0.001314	0.000668	0.000000	0.000000	0.000000	0.003734
B	WNW	0.001252	0.001381	0.000691	0.000000	0.000000	0.000000	0.003324
B	NW	0.000747	0.000629	0.000606	0.000000	0.000000	0.000000	0.001982
B	NNW	0.000561	0.000601	0.000404	0.000000	0.000000	0.000000	0.001567

TABLE 34 (continued)

Stability Class	Direction	Wind Speed (Knots) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	>21	Total
C	N	0.000494	0.000983	0.001707	0.000539	0.000118	0.000006	0.003846
C	NNE	0.000432	0.000853	0.001095	0.000314	0.000067	0.000000	0.002763
C	NE	0.000590	0.000960	0.000943	0.000219	0.000028	0.000000	0.002740
C	ENE	0.001387	0.002223	0.001651	0.000309	0.000045	0.000006	0.005620
C	E	0.001589	0.003038	0.002089	0.000365	0.000112	0.000006	0.007198
C	ESE	0.001258	0.002549	0.002437	0.000522	0.000140	0.000034	0.006940
C	SE	0.000932	0.002240	0.002684	0.000601	0.000208	0.000039	0.006704
C	SSE	0.000741	0.002055	0.003773	0.001465	0.000438	0.000118	0.008591
C	S	0.000713	0.002167	0.003156	0.001084	0.000326	0.000062	0.007507
C	SSW	0.000629	0.001814	0.002970	0.000809	0.000112	0.000017	0.006350
C	SW	0.000932	0.002145	0.002184	0.000444	0.000028	0.000006	0.005738
C	WSW	0.001342	0.002892	0.002746	0.000387	0.000118	0.000017	0.007501
C	W	0.001701	0.003172	0.002948	0.000578	0.000225	0.000051	0.008675
C	WNW	0.001319	0.003285	0.004559	0.001084	0.000460	0.000168	0.010876
C	NW	0.000691	0.001791	0.003156	0.000938	0.000371	0.000101	0.007047
C	NNW	0.000472	0.001084	0.002252	0.000837	0.000348	0.000095	0.005087
D	N	0.000758	0.001960	0.008883	0.014655	0.004756	0.001005	0.032016
D	NNE	0.000848	0.001696	0.006850	0.008647	0.002504	0.000483	0.021028
D	NE	0.001252	0.002128	0.006727	0.006339	0.001859	0.000623	0.018928
D	ENE	0.001578	0.003565	0.013099	0.010062	0.003262	0.000758	0.032325
D	E	0.002223	0.004340	0.017198	0.015368	0.004352	0.001039	0.044520
D	ESE	0.001595	0.003543	0.013425	0.013914	0.004127	0.001241	0.037844
D	SE	0.001218	0.002398	0.012229	0.013565	0.004093	0.000971	0.034475
D	SSE	0.000938	0.002583	0.012751	0.022920	0.008243	0.001830	0.049265
D	S	0.000955	0.001971	0.006783	0.012021	0.003504	0.000617	0.025750
D	SSW	0.000780	0.001488	0.005166	0.006103	0.001129	0.000084	0.014750
D	SW	0.000966	0.001460	0.004514	0.004155	0.000590	0.000084	0.011769
D	WSW	0.001028	0.001915	0.005261	0.005110	0.001106	0.000354	0.014773
D	W	0.001392	0.002263	0.006917	0.011134	0.004666	0.002021	0.028394
D	WNW	0.001544	0.003032	0.012931	0.029113	0.014941	0.006715	0.068277
D	NW	0.001174	0.002156	0.011988	0.030315	0.017961	0.009023	0.072606
D	NNW	0.000837	0.001842	0.009888	0.024324	0.012493	0.004969	0.054352

TABLE 34 (continued)

Stability Class	Direction	Wind Speed (Knots) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	>21	Total
E	N	0.000000	0.001522	0.002263	0.000000	0.000000	0.000000	0.003784
E	NNE	0.000000	0.001297	0.001353	0.000000	0.000000	0.000000	0.002650
E	NE	0.000000	0.002044	0.001950	0.000000	0.000000	0.000000	0.004003
E	ENE	0.000000	0.005323	0.007911	0.000000	0.000000	0.000000	0.013234
E	E	0.000000	0.006294	0.006985	0.000000	0.000000	0.000000	0.013279
E	ESE	0.000000	0.004599	0.004211	0.000000	0.000000	0.000000	0.008810
E	SE	0.000000	0.003902	0.005076	0.000000	0.000000	0.000000	0.008978
E	SSE	0.000000	0.002583	0.004745	0.000000	0.000000	0.000000	0.007327
E	S	0.000000	0.002094	0.002358	0.000000	0.000000	0.000000	0.004453
E	SSW	0.000000	0.001398	0.001589	0.000000	0.000000	0.000000	0.002987
E	SW	0.000000	0.001943	0.002223	0.000000	0.000000	0.000000	0.004166
E	WSW	0.000000	0.003172	0.003425	0.000000	0.000000	0.000000	0.006597
E	W	0.000000	0.002981	0.005059	0.000000	0.000000	0.000000	0.008040
E	WNW	0.000000	0.003594	0.009893	0.000000	0.000000	0.000000	0.013487
E	NW	0.000000	0.002364	0.006491	0.000000	0.000000	0.000000	0.008855
E	NNW	0.000000	0.001465	0.002942	0.000000	0.000000	0.000000	0.004408
F	N	0.003431	0.001752	0.000000	0.000000	0.000000	0.000000	0.005183
F	NNE	0.003178	0.001392	0.000000	0.000000	0.000000	0.000000	0.004570
F	NE	0.005205	0.002740	0.000000	0.000000	0.000000	0.000000	0.007945
F	ENE	0.009708	0.009321	0.000000	0.000000	0.000000	0.000000	0.019029
F	E	0.011353	0.009512	0.000000	0.000000	0.000000	0.000000	0.020865
F	ESE	0.007945	0.006508	0.000000	0.000000	0.000000	0.000000	0.014453
F	SE	0.006727	0.005334	0.000000	0.000000	0.000000	0.000000	0.012061
F	SSE	0.006042	0.003290	0.000000	0.000000	0.000000	0.000000	0.008332
F	S	0.004846	0.002454	0.000000	0.000000	0.000000	0.000000	0.007299
F	SSW	0.003925	0.002223	0.000000	0.000000	0.000000	0.000000	0.006148
F	SW	0.006345	0.003448	0.000000	0.000000	0.000000	0.000000	0.009792
F	WSW	0.009214	0.006845	0.000000	0.000000	0.000000	0.000000	0.016058
F	W	0.010606	0.006800	0.000000	0.000000	0.000000	0.000000	0.017406
F	WNW	0.008484	0.006985	0.000000	0.000000	0.000000	0.000000	0.015469
F	NW	0.005722	0.004009	0.000000	0.000000	0.000000	0.000000	0.009731
F	NNW	0.004003	0.001774	0.000000	0.000000	0.000000	0.000000	0.005778

Long-Term Diffusion Modeling

The CDM model determines long-term (seasonal/or annual) quasi-stable pollutant concentrations at any ground level receptor using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability for the same period. The equations for calculation of long-term ground level contaminant concentrations utilized in the CDM are presented in Figure 28.

The CDM model takes into account the possibility of air contaminant removal by physical or chemical processes by incorporating a decay equation into the program. This anticipated air contaminant half-life, in hours, can be included into the model. The following half-lives were used for the modeling analysis of TSP, SO_2, and NO_2:

TSP - infinite
SO_2 - 24 hours
NO_2 - 4 hours

The meteorological input for the CDM model is from the STAR Program obtained from the National Climatic Center (NCC), Asheville, North Carolina. This computer card input is derived from eleven years of data (1964-1974) from the Bismarck weather station. It consists of a joint frequency of wind speed/wind direction distribution by Pasquill Stability Classes for a

FIGURE 28

EQUATIONS FOR CALCULATION OF LONG-TERM CONCENTRATIONS

The average concentration $\overline{C}_A$ due to area sources at a particular receptor is given by

$$\overline{C}_A = \frac{16}{2\pi} \int_0^\infty \left[\sum_{k=1}^{16} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi(k, \ell, m) S(\rho, z; U_\ell \; P_m) \right] d\rho \qquad (1)$$

where k = index identifying wind direction sector

$q_k(\rho) = \int Q(\rho,\theta)\, d\theta$ for the k sector

$Q(\rho,\theta)$ = emission rate of the area source per unit area and unit time

ρ = distance from the receptor to an infinitesimal area source

θ = angle relative to polar coordinates centered on the receptor

ℓ = index identifying the wind speed class

m = index identifying the class of the Pasquill stability category

$\phi(k, \ell, m)$ = joint frequency function

$S(\rho, z; U_\ell, P_m)$ = dispersion function defined in Equations 3 and 4

z = height of receptor above ground level

U_ℓ = representative wind speed

P_m = Pasquill stability category

For point sources, the average concentration $\overline{C}_p$ due to n point sources is given by

$$\overline{C}_p = \frac{16}{2\pi} \sum_{n=1}^{n} \sum_{\ell=1}^{6} \sum_{m=1}^{6} \frac{\phi(k_n, \ell, m) G_n S(\rho_n, z; U_\ell, P_m)}{\rho_n} \qquad (2)$$

where k_n = wind sector appropriate to the n^{th} point source

G_n = emission rate of the n^{th} point source

ρ_n = distance from the receptor to the n^{th} point source

If the receptor is presumed to be at ground level, that is, $z = 0$, then the functional form of $S(\rho, z; U_\ell, P_m)$ will be

$$S(\rho, 0; U_\ell, P_m) = \frac{2}{\sqrt{2\pi}\, U_\ell \sigma_z(\rho)} \exp\left[-\frac{1}{2} \left(\frac{h}{\sigma_z(\rho)}\right)^2\right] \exp\left(\frac{-0.692\rho}{U_\ell T_{\frac{1}{2}}}\right) \qquad (3)$$

if $\sigma_z(\rho) \leq 0.8\,L$ and

$$S(\rho, 0; U_\ell, P_m) = \frac{1}{U_\ell L} \exp\left(\frac{-0.692\rho}{U_\ell T_{\frac{1}{2}}}\right) \qquad (4)$$

if $\sigma_z(\rho) > 0.8\,L$. New terms in Equations 3 and 4 are defined as follows:

$\sigma_z(\rho)$ = vertical dispersion function, i.e., the standard deviation of the pollution concentration in the vertical plane

h = effective stack height of source distribution, i.e., the average height of area source emissions in the k^{th} wind direction sector at radial distance ρ from the receptor

L = the afternoon mixing height

$T_{\frac{1}{2}}$ = assumed half life of pollutant, hours

The possibility of pollutant removal by physical or chemical processes is included in the program by the decay expression $\exp(-0.692\rho/U_\ell T_{\frac{1}{2}})$.

The total concentration for the averaging period is the sum of concentrations of the point and area sources for that averaging period.

1/Source: Climatological Dispersion Model Users Guide, US EPA, 1974 year's period of time. This information is also available for seasonal and monthly averaging time intervals.

In the course of the analysis of the effects of proposed energy development on the ambient air quality of the study area, several assumptions were made. Calculations of the 1-hour nitrogen dioxide (NO_2) concentrations assume that 100% of the nitrogen oxide (NO_x) emissions from both the boiler stack and vehicle engine exhaust is nitrogen dioxide. Studies have shown that 10% of the NO_x is actually NO_2 with the remainder as nitric oxide (NO). These studies have addressed the proportion of NO_2 in NO_x from boiler units, vehicles, and other sources and is extensively discussed in Williamson (1973) and Perkins (1974). Annual concentration calculations assume all NO_x is composed of NO_2.

Short-term highest concentrations were determined using the above diffusion models and hypothetical combinations of meteorological data that were judged reasonable for that climatic region. Worst case normal dispersion, limited mixing and inversion breakup situations were considered and 1-hour, 3-hour and 24-hour average concentrations were calculated.

Particulates

Air dispersion modeling techniques were used to estimate impacts on the seven county study area from particulate matter based on the emission values presented in Tables 9, 10, and 11. These modeling estimates were compared to the State Ambient Air Quality Standards and Prevention of Significant Deterioration of Air Quality Regulations, as previously described, to determine if these standards would be met. Annual and short-term (24-hour) ground level concentration estimates were used to be consistent with the averaging times stated in the Ambient Air Quality Standards and Prevention of Significant Deterioration of Air Quality Regulations.

Table 35 presents the background concentration level for total suspended particulates used in the air dispersion modeling analysis. These background levels were derived from the North Dakota State Department of Health air quality monitoring stations located in the seven county study area and are representative of the existing air quality in the seven county study area.

TABLE 35

BACKGROUND AIR QUALITY
Total Suspended Particulates

Annual Geometric Mean Concentration 1/	24-Hour Geometric Mean Concentration
25	80

SOURCE: North Dakota State Department of Health 1977.

1/ Measured background values near Beulah, ND. All values in micrograms per cubic meter of air ($\mu g/m^3$).

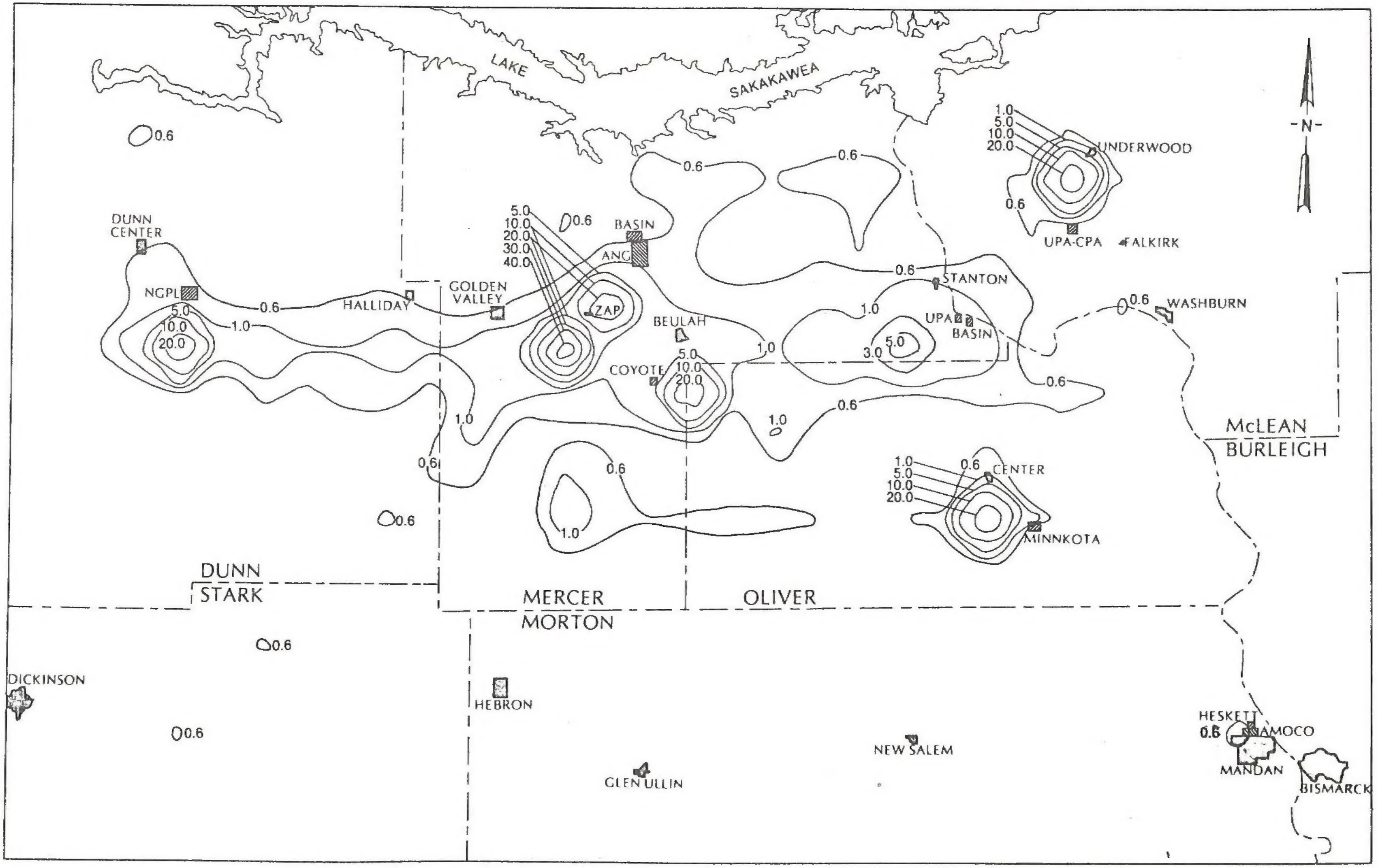
Figure 29 presents the annual estimated ground level concentrations for total suspended particulates from the proposed Level 1 and existing facilities in the seven county area.

Open pit mining operations typically have high total suspended particulate concentrations in the immediate area of the mining activities. These high localized concentrations decrease very rapidly as the distance from the mining activities increases as illustrated in Figure 29. Only those values occurring outside of the boundaries of privately owned industrial property are subject to state and federal regulations.

As a result of mining operations and all proposed electrical generation and gasification facilities, the maximum total suspended particulate concentration would be projected to occur near Zap in Mercer County. The maximum estimated annual ground level concentration was determined to be 2.0 micrograms per cubic meter of air. The addition of this projected concentration to the existing annual particulate background of 25 micrograms per cubic meter of air would yield a total maximum annual concentration of 27 micrograms per cubic meter of air. This value is less than the annual maximum allowable total suspended particulate concentration Ambient Air Quality Standard of 60 micrograms per cubic meter of air. The projected 2 micrograms per cubic meter of air concentration for particulates is also less than the annual Class II Prevention of Significant

Figure 29

PROJECTED ANNUAL SUSPENDED PARTICULATE CONCENTRATIONS FROM MAJOR EXISTING AND PROPOSED SOURCES.



▨ Major existing and proposed sources

—— Isolines show total suspended particulate concentrations in micrograms per cubic meter of air.

▩ Towns and cities

4 0 4 8
Scale in Miles

SOURCE: North Dakota State Department of Health, 1977.

Deterioration of Air Quality increment of 10 micrograms per cubic meter of air.

Projected particulate concentrations due to Level 1 proposals, when added to existing air quality particulate concentrations in the seven county study area would be less than both the Ambient Air Quality Standards and the Prevention of Significant Deterioration of Air Quality Regulations.

A short-term (24-hour) dispersion analysis was also performed for total suspended particulates. The maximum short-term (24-hour) ground level concentration for particulate matter was projected to occur approximately one-tenth of a mile north of the proposed American Natural Gas Company and Basin Electric Antelope Valley facility site boundaries. This concentration is expected to result from the interaction of the proposed American Natural Gas Company coal gaisification plant, Basin Electric Antelope Valley Station Unit 1 and Unit 2, and Montana-Dakota Utilities Coyote Station Unit 1. This maximum would occur only when the wind direction is from the south and would result in an increase of 5.3 micrograms per cubic meter of air for a 24-hour averaging time.

The 5.3 micrograms per cubic meter of air concentration is less than the 24-hour Class II Prevention of Significant Deterioration of Air Quality Regulation allowable increment of 30 micrograms per cubic meter of air for particulate matter.

With the addition of the projected maximum short-term concentration to the 24-hour background value of 80 micrograms per cubic meter of air, a total concentration of 85.3 micrograms per cubic meter of air was obtained. This value is less than the maximum allowable 24-hour Ambient Air Quality Standard of 150 micrograms per cubic meter of air.

Particulate emissions would result from the additional proposed Level 2 projects. All of the Level 2 proposals are categorized as area-wide particulate emission sources with the exception of the Montana-Dakota Utilities Company Coyote 2 electrical generating facility which is considered as a point source.

The existing North Dakota and Federal Ambient Air Quality Standards for maximum allowable particulate ambient air concentrations are expected to remain applicable to the additional Level 2 proposed projects. In addition, the allowable increment for increase in particulate ambient air concentrations under the designation for Class II of the State Prevention of Significant Deterioration of Air Quality Regulations would be applicable to these developments.

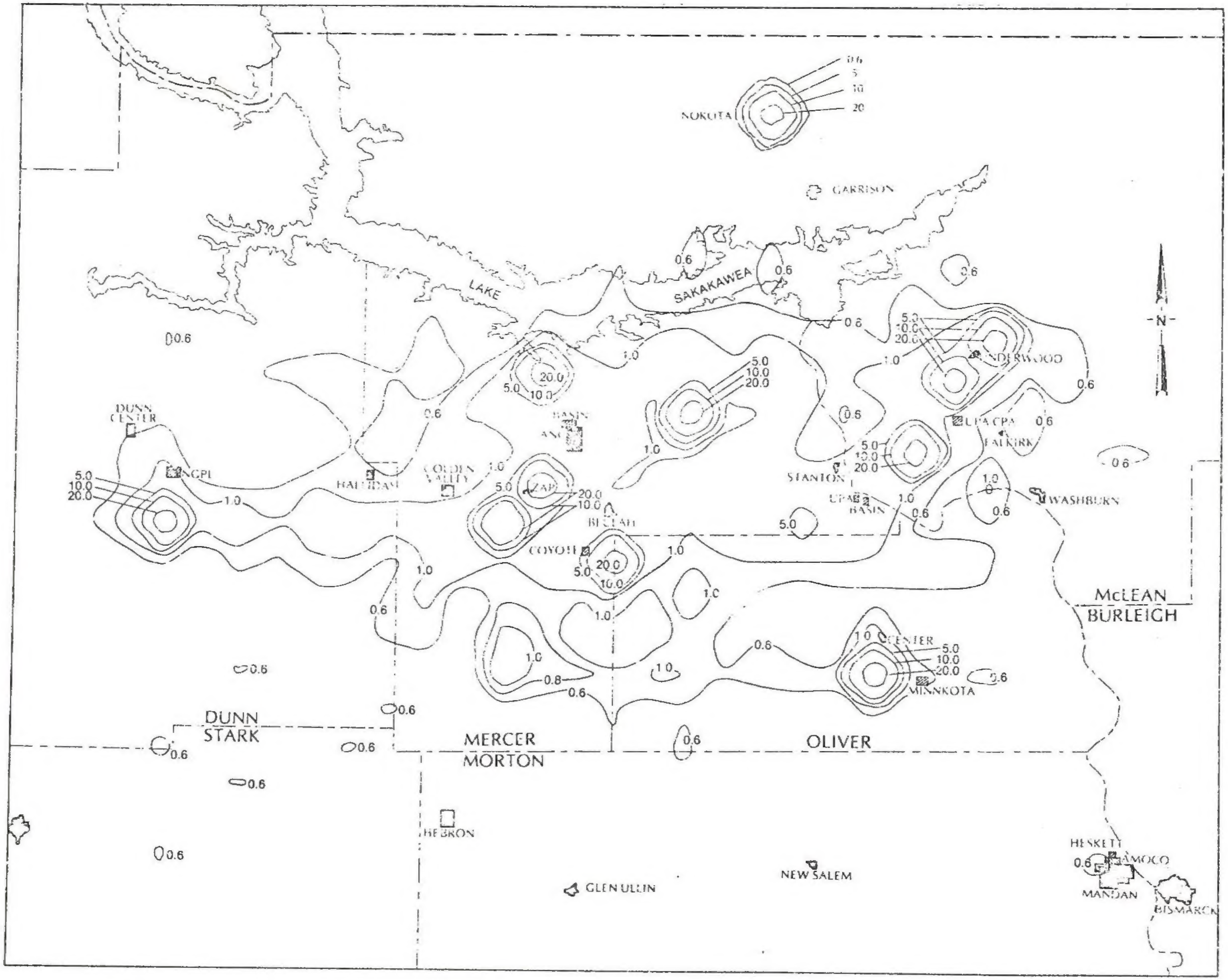
Fugitive dust from the additional Level 2 proposed mining projects would be expected to be the primary cause of atmospheric particulate loading. The sources which would be the major contributors to fugitive dust include: construction equipment during road and rail building, loose spoil and topsoil piles prior to reshaping and planting, mining equipment operations, blasting, coal crushing and loading, and loss of coal fines during transport and stockpiling. The proposed Coyote 2 electrical generating facility would contribute particulates to the ambient air in the seven county study area, but to a lesser extent than the proposed coal mining operations.

Air dispersion analysis performed for the proposed Level 2 projects included the projected Level 1 proposal ground level concentrations for particulates, sulfur dioxide, and nitrogen dioxide, and the addition of the existing measured background concentrations for each of these ambient air contaminants. The projected annual ground level concentrations for particulates resulting from the Level 2 (tentative plus active proposals) proposed projects are presented in Figure 30.

Maximum annual ground level concentrations of particulates, as presented in Figure 30, are projected to be 20 micrograms per cubic meter of air on the mine site property and 3.0 micrograms per cubic meter of air at the mine site boundaries. These maximum projected ground level concentrations would occur in the immediate area of the proposed Level 2 mining activities. Since the maximum projected annual ground level particulate concentration of 20 micrograms per cubic meter of air would occur within the mine site boundaries, it is not subject to state air pollution control regulation. Only those values occurring outisde of the boundaries of privately-owned

Figure 30

PROJECTED ANNUAL SUSPENDED PARTICULATE CONCENTRATIONS FROM MAJOR AND PROPOSED SOURCES — LEVEL 2



▨ Major existing and proposed sources

—— Isolines show total suspended particulate concentrations in micrograms per cubic meter of air.

▨ Towns and cities

4 0 4 8
Scale in Miles

SOURCE: North Dakota State Department of Health, 1977.

industrial property are subject to state air pollution control regulation.

The projected annual maximum ground level concentration of particulates resulting from the proposed Coyote 2 electrical generating facility would be undistinguishable as a contributor to the ambient air particulate loading resulting from all Level 2 proposals. The resulting projected maximum ambient air particulate concentration from mining operations of approximately 3.0 micrograms per cubic meter of air outside of the mines boundaries would be less than the annual State Prevention of Significant Deterioration of Air Quality Regulation increment of 10 micrograms per cubic meter of air. The addition of the projected maximum ground level concentration of approximately 3.0 micrograms per cubic meter of air to the existing annual background concentration of 25 micrograms per cubic meter of air is less than the maximum allowable geometric mean total suspended particulate State Ambient Air Quality Standard concentration of 60 micrograms per cubic meter of air.

The short-term (24-hour) maximum ground level concentrations for particulates occurring in the seven county study area as a result of the proposed Coyote 2 electrical generating facility would increase the projected Level 1 short-term concentration of 5.3 micrograms by 1.7 micrograms per cubic meter of air giving a total of 7.0 micrograms per cubic meter of air. In addition, the particulate contributions to the ambient air resulting from the five additional proposed Level 2 mining operations would be localized, usually occurring in the immediate area of mining activity. This would not cause a measurable increase in ambient air particulate concentrations over that described for Level 1 proposals outside of the mining site boundaries.

Sulfur Dioxide

Sulfur dioxide emissions to the ambient air in the seven county study area would result primarily from the proposed Level 1 point source projects. It is assumed that the existing North Dakota and Federal Ambient Air Quality Standards for allowable ambient air concentrations of sulfur dioxide would remain unchanged during the time period when proposed Level 1 point source projects would be constructed and become operational.

Sulfur dioxide emissions from fossil fuel-fired steam generators are regulated under the New Source Performance Standards promulgated by both the state and federal government. Both the state and federal New Source Performance Standards limit the permissible sulfur dioxide emission concentrations from solid fuels to 1.2 pounds per million British thermal unit heat input, and 0.8 pounds per million British thermal unit heat input from liquid fuels.

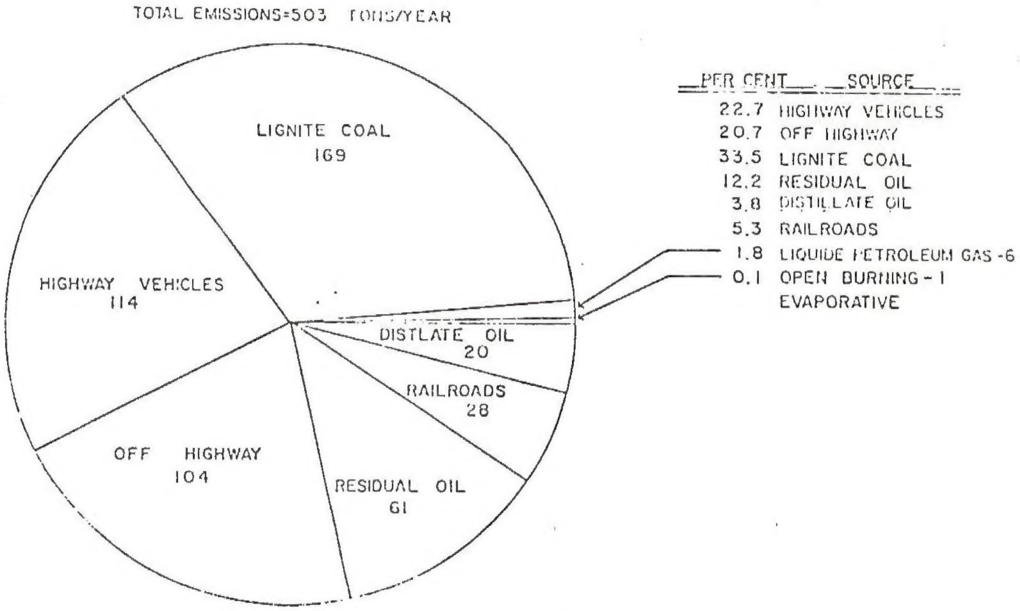
Under the Prevention of Significant Deterioration of Air Quality Regulations, western North Dakota, including the seven county study area, has been designated as Class II for allowable increments of sulfur dioxide contributions to the ambient air.

The expected area source sulfur dioxide emissions for Oliver, Mercer, McLean, and Dunn Counties in the seven county study area in 1980 are presented in Figure 31. The total expected sulfur dioxide contribution from area sources is projected to be 503 tons per year. Sulfur dioxide contributions from proposed point sources during Level 1 projected phase of development are expected to be approximately 82,516 tons per year at full capacity. From this data, it appears that the contribution of sulfur dioxide from the proposed Level 1 projects would constitute the major sulfur dioxide sources affecting the air quality in the seven county study area.

Air dispersion modeling techniques were used to estimate impacts upon the seven county study area from sulfur dioxide, based on the emissions presented in Tables 9, 10, and 11. These modeling estimates were compared to the State Ambient Air Quality Standards and State Prevention of Significant Deterioration of Air Quality Regulations. Annual and short-term (1-hour, 3-hour, 24-hour) estimates were used as averaging times to be consistent with the State Ambient Air Quality Standards and State Prevention of Significant Deterioration of Air Quality Regulations.

FIGURE 31

1980 AREA SOURCE SULFUR DIOXIDE EMISSION FOR OLIVER, MERCER McLEAN AND DUNN COUNTIES WITHIN THE STUDY AREA



Source: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

Table 36 presents the background concentration levels for sulfur dioxide used in the air dispersion analysis. These levels were derived from data collected by the North Dakota State Department of Health air quality monitoring stations located in the seven county study area. Figure 32 presents the ground level concentrations of sulfur dioxide in the study area from all existing point sources.

TABLE 36

AMBIENT AIR QUALITY BACKGROUND
SULFUR DIOXIDE

Annual 1/ Concentration	1-Hour Concentration	3-Hour Concentration	24-Hour Concentration
5	105	35	25

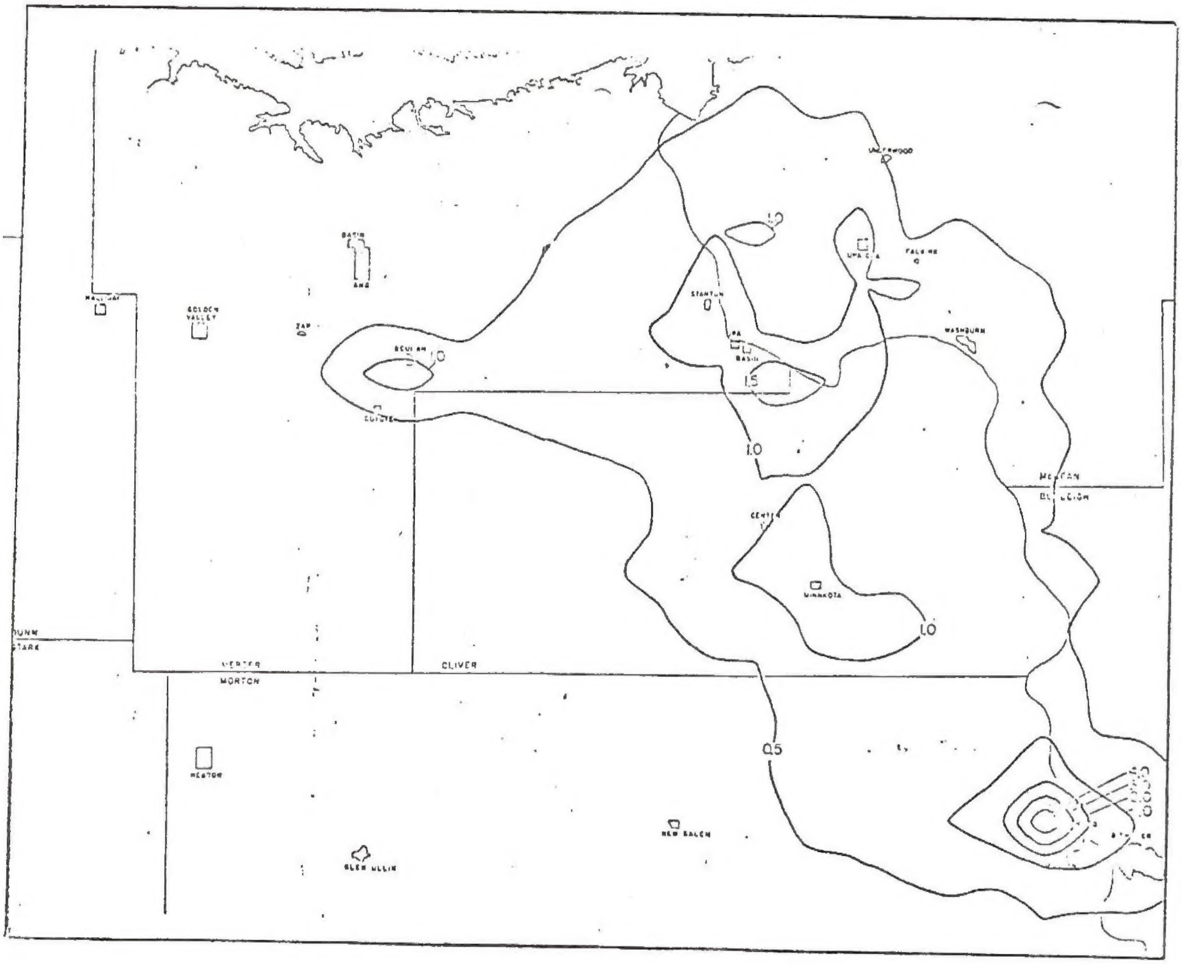
SOURCE: North Dakota State Department of Health 1977.

1/ Measured background values near Beulah, ND. All values in micrograms per cubic meter of air ($\mu g/m^3$) arithmetic mean values.

Figure 33 presents the annual estimated ground level concentrations for sulfur dioxide from the proposed Level 1 facilities. All existing energy conversion facilities, as well as the Level 1 proposals, were considered. The highest predicted ground level concentration would occur in the Mandan area with a maximum of 5 micrograms per cubic meter of air. This 5 micrograms per cubic meter of air is due to the contribution of existing sources in the Mandan area.

FIGURE 32

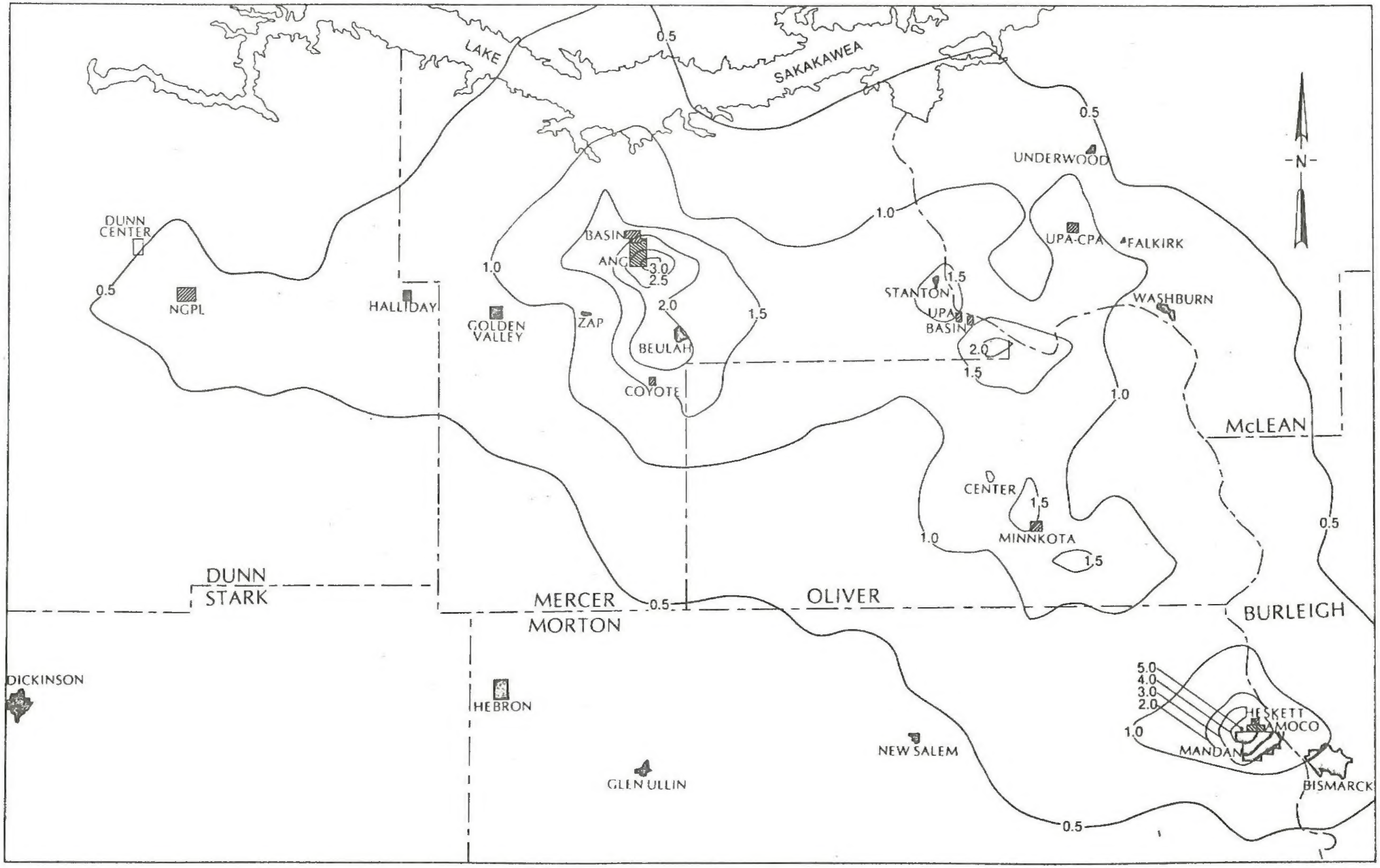
MAXIMUM PROJECTED ANNUAL GROUND LEVEL CONCENTRATION OF SO_2 FROM EXISTING SOURCES



SOURCE: North Dakota State Department of Health 1977

Figure 33

PROJECTED ANNUAL CONCENTRATIONS OF SULFUR DIOXIDE FROM ALL EXISTING AND PROPOSED SOURCES



▨ Major existing and proposed sources

— Isolines show total sulfure dioxide concentrations in micrograms per cubic meter of air.

▩ Towns and cities

4 0 4 8
Scale in Miles

SOURCE: North Dakota State Department of Health, 1977.

The contribution of sulfur dioxide to the air quality from proposed Level 1 sources is reflected by the various ground level projected increases around the individual proposed Level 1 projects. The maximum ground level concentration sulfur dioxide from proposed Level 1 sources, occurred in an area south of the proposed American Natural Gas Company coal gasification plant and the Basin Antelope Valley complex. This ground level concentration was estimated to be 3.1 micrograms per cubic meter of air. The addition of this projected concentration to the existing annual sulfur dioxide background of 5 micrograms per cubic meter of air would yield a total maximum annual concentration of 8.1 micrograms per cubic meter of air. This value is less than the annual maximum allowable sulfur dioxide concentration North Dakota Ambient Air Quality Standard of 60 micrograms per cubic meter of air. This estimated maximum ground level concentration of sulfur dioxide also is less than the annual Class II Prevention of Significant Deterioration of Air Quality Regulations increment of 15 micrograms per cubic meter of air.

Projected sulfur dioxide concentrations due to Level 1 proposals, when added to existing air quality sulfur dioxide concentrations in the seven county study area, would be less than both the State Ambient Air Quality Standards and the State Prevention of Significant Deterioration of Air Quality Regulations.

The short-term (1-hour, 3-hour, 24-hour) projected ground level concentrations for sulfur dioxide emissions from proposed Level 1 projects are presented in Table 37. The highest projected ground level concentrations were in and around the proposed American Natural Gas Company coal gasification complex, the Basin Antelope Valley Station Unit 1 and Unit 2 electrical generating facility, and the Coyote Station Unit 1 electrical generating facility. These maximum concentrations are projected to occur when the wind direction is from the south.

A projected 1-hour maximum ground level concentration of 280.4 micrograms per cubic meter of air for sulfur dioxide was found to occur 1.2 miles north of the proposed American Natural Gas Company coal gasification and Basin Antelope Valley facilities. The addition of this projected concentration to the existing background sulfur dioxide level of 105 micrograms per cubic meter of air would yield a total maximum 1-hour concentration of 385.4 micrograms per cubic meter of air. This value is less than the maximum allowable 1-hour State Ambient Air Quality Standard of 715 micrograms per cubic meter of air for sulfur dioxide.

The maximum 3-hour ground level concentration of sulfur dioxide which would occur in the study area as a result of proposed Level 1 development is projected to be 174.5 micrograms per cubic meter of air. This projected concentration is less than the 3-hour Class II Prevention of Significant Deterioration of

TABLE 37

SHORT TERM SULFUR DIOXIDE ANALYSIS
Level 1 Proposed Projects

Atmospheric Stability Class[1]	Distance From North of American Natural Gas[2] Basin Complex Boundary (miles)	Projected Concentration[3] (μg/m³)[4]			Background Concentration (μg/m³)			Total Concentration (μg/m³)			
		1 Hr	3 Hr	24 Hr	1 Hr	3 Hr	24 Hr	1 Hr	3 Hr	24 Hr	
A	on site boundary	280.4	174.5	68.5	105	35	25	(385.4)[5]	174.5	68.5	(93.5)
B	1.2	117.9	73.4	28.8	105	35	25	(222.9)	73.4	28.8	(53.8)
C	3[6]	212.3	129.5	51.0	105	35	25	(317.3)	129.5	51.0	(76.0)
D	8	137.5	84.9	34.0	105	35	25	(242.5)	84.9	34.0	(59.0)
E	39	111.1	68.5	27.4	105	35	25	(216.1)	111.1	68.5	(52.4)
F[7]	--	--	--	--	--	--	--	--	--	--	--
State Ambient Air Quality Standards (includes background values)								715			260
State Class II Prevention of Significant Deterioration Standards (increments above background values)									700	100	

SOURCE: North Dakota State Department of Health 1977

1/ The stability class is a measure of the ability of the atmosphere to disperse emissions. Generally, Classes A, B, C, and D favor rapid dispersion whereas the more stable classes, E and F are associated with poor dispersion.

2/ American Natural Gas concentrations based on normal operation conditions.

3/ All concentrations are maximums for given stability class.

4/ Micrograms per cubic meter of air.

5/ Numbers in parenthesis have background added in and are to be compared to Ambient Air Quality Standards. Numbers without parenthesis are counted against Prevention of Significant Deterioration of Air Quality increments.

6/ This maximum concentration occurred with the wind from the north; therefore, ground level concentration is projected to occur south of the Coyote site boundary.

7/ The projected concentrations under F Stability Class were found to be lower than those concentrations under E Stability Class for all cases. Also, the distance to the point of maximum concentration is so great that meteorological conditions are not likely to persist long enough for the plume to travel this far.

Air Quality Regulation established increment of 700 micrograms per cubic meter of air. The addition of this projected concentration of 174.5 micrograms per cubic meter of air to the existing background of 35 micrograms per cubic meter of air would yield a total maximum 3-hour concentration of 209.5 micrograms per cubic meter of air which is less than the maximum allowable Federal Secondary Ambient Air Quality Standard of 1300 micrograms per cubic meter of air.

The maximum 24-hour projected ground level concentration of sulfur dioxide in the seven county study area that would result from proposed Level 1 development is projected to be 68.5 micrograms per cubic meter of air. This value is less than the 24-hour allowable concentration for sulfur dioxide of 100 micrograms per cubic meter of air as established in the Class II Prevention of Significant Deterioration of Air Quality Regulations. The maximum projected 24-hour ground level concentration, when added to the measured background value of 25 micrograms per cubic meter of air would yield a total concentration of 93.5 micrograms per cubic meter of air. This total concentration would be less than the established 24-hour State Ambient Air Quality Standard for the maximum permissible concentration for sulfur dioxide of 260 micrograms per cubic meter of air. This indicates that all State and Federal Ambient Air Quality Standards as well as the State Prevention of Significant Deterioration of Air Quality Regulations for sulfur dioxide would not be exceeded.

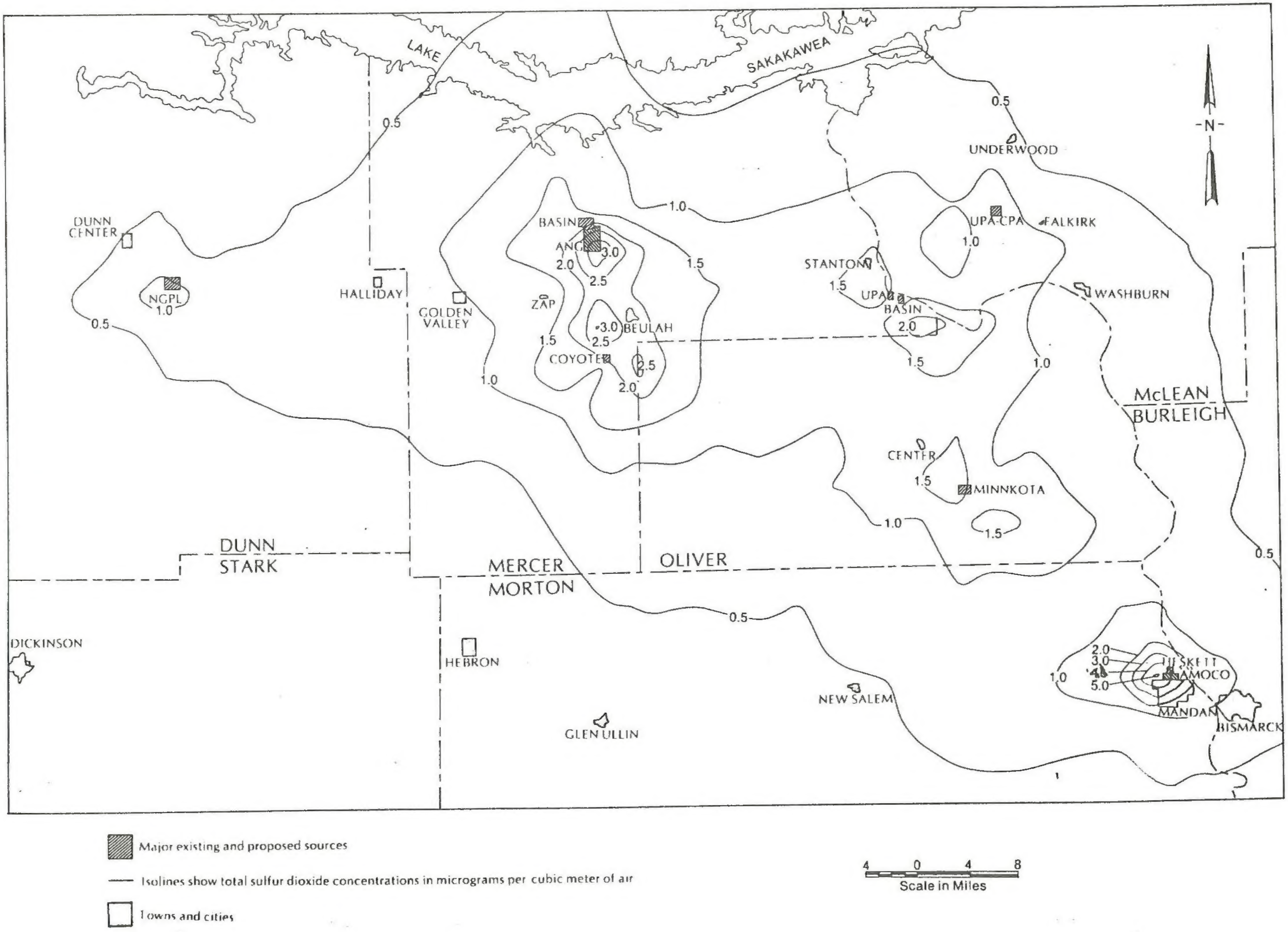
The sulfur dioxide ambient air contributions from the additional Level 2 mining projects are expected to be negligible. These proposed additional Level 2 projects constitute area sources and would not be expected to involve energy conversion operations that would emit measurable quantities of sulfur dioxide in the ambient air. The Coyote 2 electrical generating facility would be the only Level 2 major source of sulfur dioxide emission to the ambient air in the seven county study area.

The maximum projected ground level concentration for sulfur dioxide resulting from the proposed Coyote 2 electrical generating facility in addition to the projected ground level sulfur dioxide concentrations from the existing and proposed Level 1 developments is presented in Figure 34. As shown, the ambient air ground level sulfur dioxide concentration occurring in the Mandan area would not be influenced as a result of the proposed Coyote facility.

The annual maximum ground level concentration for sulfur dioxide resulting from the proposed Coyote 2 facility would be 3.4 micrograms per cubic meter of air. The addition of the maximum ground level concentration of 3.4 micrograms per cubic meter of air to the existing background concentration of 5 micrograms per cubic meter of air is less than the current annual maximum allowable concentration of 60 micrograms per cubic meter of air as established by existing State Ambient Air Quality Standards. This estimated maximum ground level concentration of sulfur

Figure 34

PROJECTED ANNUAL CONCENTRATIONS OF SULFUR DIOXIDE (SO_2) FROM ALL EXISTING AND PROPOSED SOURCES — LEVEL 2



SOURCE: North Dakota State Department of Health, 1977.

dioxide also is less than the annual Class II Prevention of Significant Deterioration of Air Quality Regulation increment of 15 micrograms per cubic meter of air.

The short-term (1-hour, 3-hour, and 24-hour) projected maximum ground level concentrations for sulfur dioxide as a result of the proposed Coyote 2 electrical generating facility is presented in Table 38. The short-term analysis included all existing energy conversion facilities and Level 1 proposed projects. The maximum short-term (1-hour, 3-hour, and 24-hour) ground level concentrations of sulfur dioxide resulting from the proposed Coyote 2 facility would occur approximately six-tenths of a mile south of the facility site boundary. The maximum projected 1-hour, 3-hour and 24-hour ground level concentrations are 367.9 micrograms per cubic meter of air, 228.9 micrograms per cubic meter of air, and 89.9 micrograms per cubic meter of air, respectively.

The maximum projected 3-hour ground level concentration for sulfur dioxide is less than the maximum allowable 3-hour State Prevention of Significant Deterioration of Air Quality Regulations increment of 700 micrograms per cubic meter of air for a Class II area. Also, the maximum projected 24-hour ground level concentration is less than the maximum allowable 24-hour State Prevention of Significant Deterioration of Air Quality Regulations increment of 100 micrograms per cubic meter of air for a Class II area. The addition of the existing measured

TABLE 38

SHORT TERM SULFUR DIOXIDE ANALYSIS
Level 2 Proposed Projects

Atmospheric Stability Class[1]	Distance South from of the Coyote Boundary (miles)	Projected Concentrations ($\mu g/m^3$)[2]			Background Concentration ($\mu g/m^3$)			Total Concentration ($\mu g/m^3$)		
		1-Hr	3-Hr	24-Hr	1-Hr	3-Hr	24-Hr	1-Hr	3-Hr	24-Hr
A	0.6	367.9	228.9	89.9	105	35	25	(472.9)[3]	228.9	89.9 (114.9)
B	1.5	163.7	101.8	40.0	105	35	25	(268.7)	101.8	40.0 (65.0)
C	1.8	240.0	146.3	57.6	105	35	25	(345.0)	146.3	57.6 (82.6)
D	6.8	163.8	101.1	40.4	105	35	25	(268.8)	101.1	40.4 (65.4)
E	35.8[4]	144.4	89.0	35.6	105	35	25	(249.4)	89.0	35.6 (60.6)
F[5]	---	---	---	---	---	---	---	---	---	---

State Ambient Air Quality Standards (includes background values) - - - - - - - - - - - - - - - - - - -715 - - - - - - - - - -260

State Class II Prevention of Significant Deterioration Standards - 700 100 - -
(increments above background values)

SOURCE: North Dakota State Department of Health 1977

[1] The stability class is a measure of the ability of the atmosphere to disperse emissions. Generally, Classes A, B, C, and D favor rapid dispersion whereas the more stable classes, E and F, are associated with poor dispersion.

[2] All concentrations are maximums for given stability class in micrograms per cubic meter of air. American Natural Gas concentrations based on normal operation conditions.

[3] Numbers in parenthesis have background added in and are to be compared to Ambient Air Quality Standards. Numbers without parenthesis are counted against Prevention of Significant Deterioration of Air Quality increments.

[4] This maximum concentration occurred with the wind from the south; therefore, ground level concentration is projected to occur north of the American Natural Gas, Basin site.

[5] The projected concentrations under F Stability Class were found to be lower than those concentrations under E Stability Class for all cases. Also, the distance to the point of maximum concentrations is so great that meteorological conditions are not likely to persist long enough for the plume to travel this far.

background concentrations for sulfur dioxide would give total values of 472.9 micrograms per cubic meter of air for the 1-hour averaging time period, and 114.9 micrograms per cubic meter of air for the 24-hour averaging time period. Both of these projected total concentration values would be less than the maximum allowable 1 and 24-hour State Ambient Air Quality Standard values of 715 micrograms per cubic meter of air and 260 micrograms per cubic meter of air, respectively.

Oxides of Nitrogen

The oxides of nitrogen, expressed as equivalent nitrogen dioxide concentrations, contributed to the ambient air in the seven county study area would result primarily from the proposed Level 1 point source projects. Area sources are also expected to contribute small concentrations of nitrogen dioxide emissions to the ambient air. The nitrogen dioxide emissions originate from increased vehicle traffic, both on and off highways, and from the operation of heavy construction equipment.

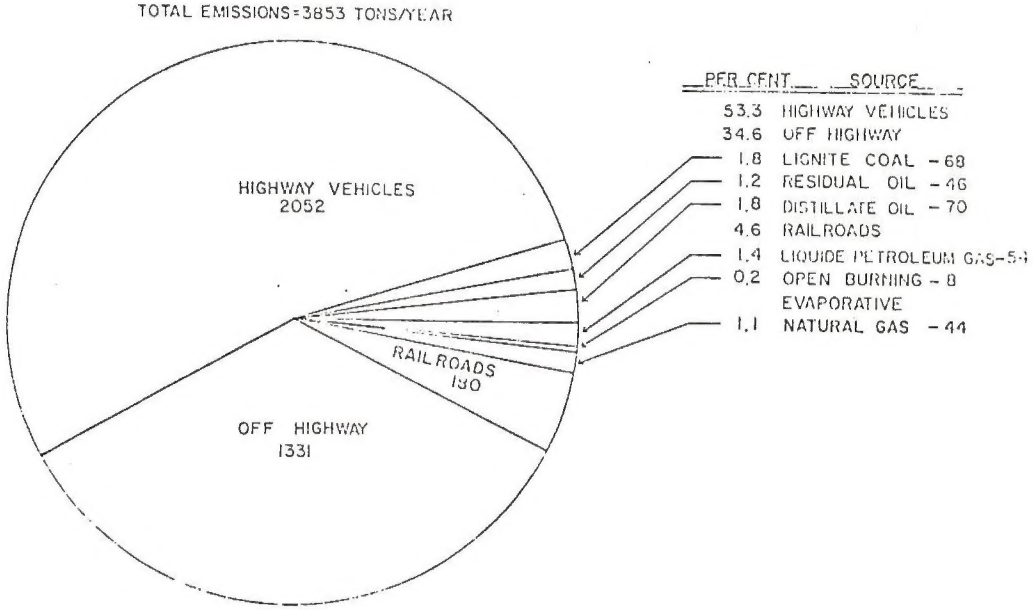
At the present time, Prevention of Significant Deterioration of Air Quality Regulations do not apply to nitrogen dioxide. Also, there are no New Source Performance Standards, either federal or state, covering the allowable nitrogen dioxide ambient air emissions from lignite coal-fired steam generating facilities. Although a New Source Performance Standard has been proposed, it is doubtful that all proposed Level 1 projects would be considered in light of that standard. The proposed Federal New Source Performance Standard for nitrogen dioxide is 0.6 pound per million British thermal unit heat input for lignite coal. It is expected that any proposed North Dakota standard concerning NO_2 will be identical to the federal standard.

The expected area source nitrogen dioxide emissions for Oliver, Mercer, McLean and Dunn Counties in the seven county study area in 1980 are presented in Figure 35. The total expected nitrogen dioxide contributions from area sources is projected to be 3853 tons per year. The expected nitrogen dioxide contribution from proposed Level 1 development during this period is approximately 44,400 tons per year. This data reveals that the contribution of nitrogen dioxide from the proposed Level 1 projects constitutes the major nitrogen dioxide source affecting air quality. Point source nitrogen dioxide contributions to the ambient air will be the primary focus for assessment of potential impacts.

The air dispersion modeling techniques used to estimate impacts of nitrogen oxides on the seven county study area assumed that all oxides of nitrogen emitted to the ambient air from existing and proposed energy developments were as nitrogen dioxide. All maximum projected ground level concentrations for nitrogen dioxide are compared with the existing State Ambient Air Quality Standards for maximum allowable ambient air concentrations only, since there are no existing Prevention of Significant

FIGURE 35

1980 AREA SOURCE NITROGEN DIOXIDE EMISSIONS FOR OLIVER, MERCER, McLEAN AND DUNN COUNTIES IN THE STUDY AREA



Source: North Dakota Air Quality Maintenance Area Analysis
U.S. Environmental Protection Agency
EPA 908 1-76-009 (1976)

Deterioration of Air Quality Regulations concerning nitrogen dioxide emissions.

Table 39 presents the background concentration levels for nitrogen dioxide used in the air dispersion analysis. These levels were derived from air quality data collected by the North Dakota State Department of Health air quality monitoring stations located in the seven county study area.

TABLE 39

AIR QUALITY BACKGROUND
Nitrogen Dioxide (NO_2)1/

1975 Annual Concentration	1975 1-Hour Concentration
5	55

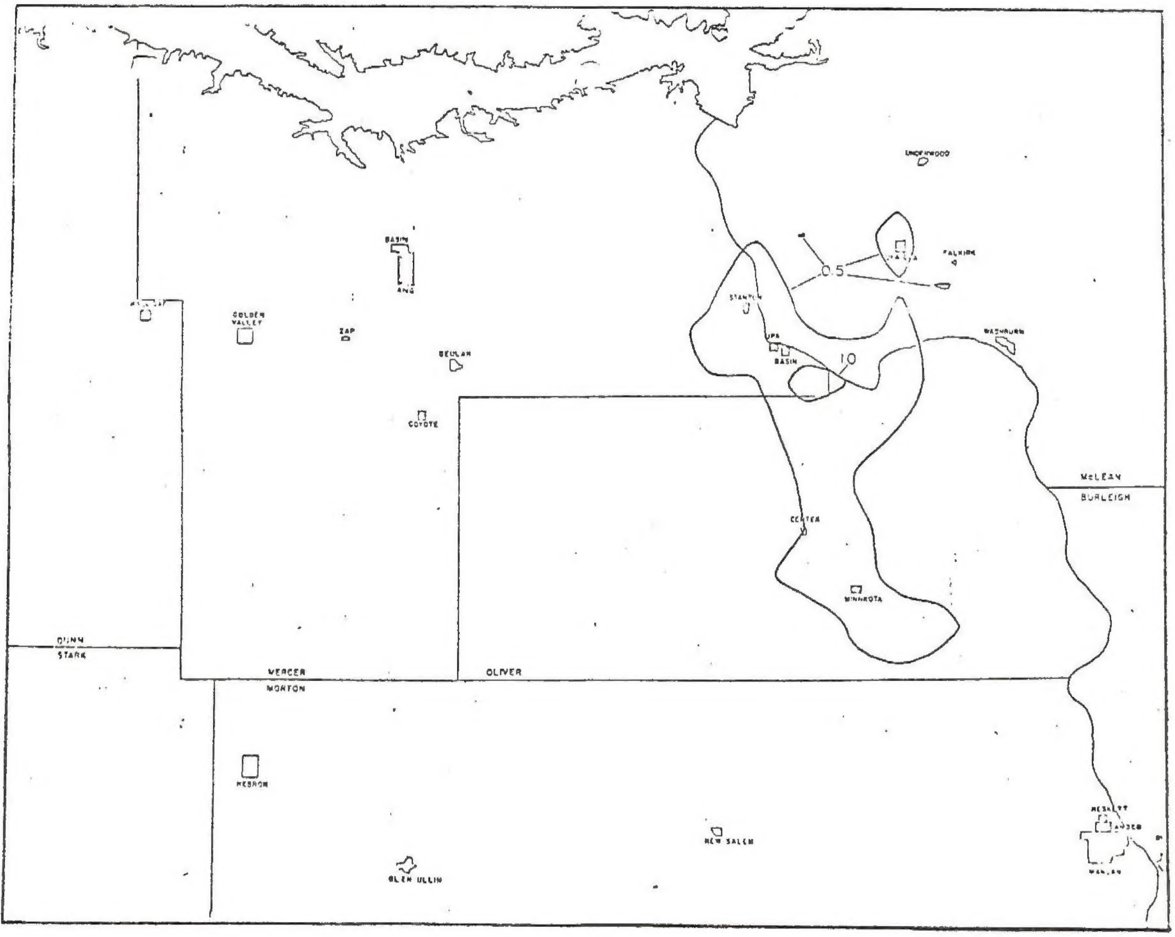
SOURCE: North Dakota State Department of Health 1977.

1/ Measured background values near Beulah, ND. All values in micrograms per cubic meter of air ($\mu g/m^3$).

As shown on Figure 36, the annual maximum projected ground level concentrations of nitrogen dioxide tend to occur around energy conversion facilities. The concentration of nitrogen dioxide in the vicinity of Stanton and Center, North Dakota, is due to existing sources. The ground level contribution of nitrogen oxides from proposed Level 1 facilities, is shown in Figure 37 as being concentrated in the Beulah area from the three Level 1 energy conversion sources proposed for that area. A similar concentration of nitrogen oxides was found to occur near the

FIGURE 36

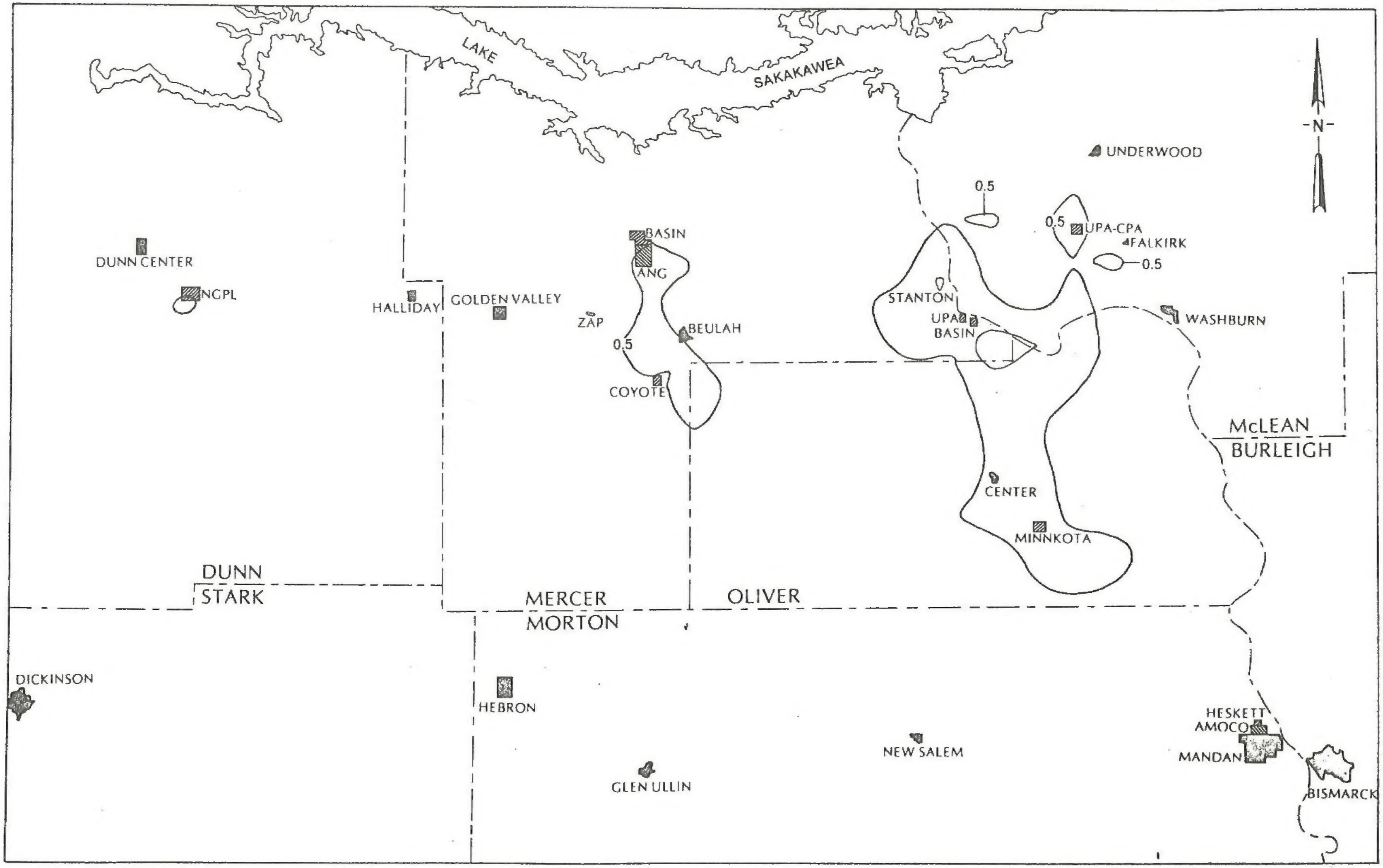
MAXIMUM PROJECTED ANNUAL GROUND LEVEL CONCENTRATIONS OF NO_2 FROM EXISTING FACILITIES



SOURCE: North Dakota State Department of Health 1977

Figure 37

PROJECTED ANNUAL CONCENTRATIONS OF NITROGEN DIOXIDE FROM ALL MAJOR EXISTING AND PROPOSED SOURCES



▨ Major existing and proposed sources

— Isolines show total nitrogen dioxide concentrations in micrograms per cubic meter of air

■ Towns and cities

4 0 4 8
Scale in Miles

SOURCE: North Dakota State Department of Health, 1977.

Natural Gas Pipeline Company of America coal gasification facility in Dunn County. The maximum projected ground level concentration, due to proposed Level 1 projects, was estimated to be 0.56 micrograms per cubic meter of air occurring near Beulah. The addition of this projected concentration to the existing background nitrogen dioxide level of 5 micrograms per cubic meter of air would yield a total annual concentration of 5.56 micrograms per cubic meter of air. This is less than the current annual maximum allowable State Ambient Air Quality Standard of 100 micrograms per cubic meter of air.

The short-term (1-hour) projected ground level concentrations for nitrogen dioxide emissions from the proposed Level 1 projects are presented in Table 40. The short-term analysis considered all proposed Level 1 projects, with the highest ground level concentration occurring on the north site boundary of the Basin Electric Power Cooperative Antelope Valley Station Unit 1 and Unit 2 electrical generating facility. In this analysis, the measured background values were added to the maximum projected ground level nitrogen dioxide 1-hour concentration.

The projected short-term (1-hour) maximum ground level concentration of 140.4 micrograms per cubic meter of air for nitrogen dioxide with the addition of the existing background value of 55 micrograms per cubic meter of air would yield a total of 195.4 micrograms per cubic meter of air in the seven

TABLE 40

SHORT TERM NITROGEN DIOXIDE ANALYSIS
Level 1 Proposed Projects

Atmospheric Stability Class 1/	Distance From North of American Natural Gas 2/ Basin Complex Boundary (miles)	Projected Concentrations 3/ ($\mu g/m^3$) One-Hour	Background Concentrations ($\mu g/m^3$) One-Hour	Total Concentration ($\mu g/m^3$) One-Hour
A	on site boundary	140.4	55.0	(195.4) 4/
B	1.2	59.0	55.0	(114.0)
C	3.0 5/	106.2	55.0	(161.2)
D	8.0	68.8	55.0	(123.8)
E	39.0	55.6	55.0	(110.6)
F 6/	--	--	--	--

State Ambient Air Quality Standard (includes background values) - - - - - - - - - - - - 200
(not to be exceeded more that 1% of the time in any three month period).

SOURCE: North Dakota State Department of Health 1977

NOTE: All Oxides of Nitrogen emissions considered to be as Nitrogen Dioxide (NO_2).

1/ The stability class is a measure of the ability of the atmosphere to disperse emissions. Generally Classes A, B, C, and D favor rapid dispersion where as the more stable Classes, E and F, are associated with poor dispersion.

2/ American Natural Gas concentrations based on normal operation conditions.

3/ All concentrations are maximums for given Stability Class in micrograms per cubic meter of air.

4/ Numbers in parenthesis are projected concentrations with background values added.

5/ This concentration occurred with the wind from the north; therefore, ground level concentration was projected to occur south of the Coyote site boundary.

6/ The projected concentrations under F Stability Class were found to be lower than those concentrations under E Stability Class for all cases. Also, the distance to the point of maximum concentration is to great that meteorological conditions are not likely to persist long enough for the plume to travel this far.

county study area as a result of the existing and proposed Level 1 projects. This value is less than the maximum allowable 1-hour State Ambient Air Quality Standard of 200 micrograms per cubic meter of air not to be exceeded over 1% of the time in any 3-month period for nitrogen dioxide. This analysis indicates that all applicable State and Federal Ambient Air Quality Standards, both annual and short-term, would not be exceeded.

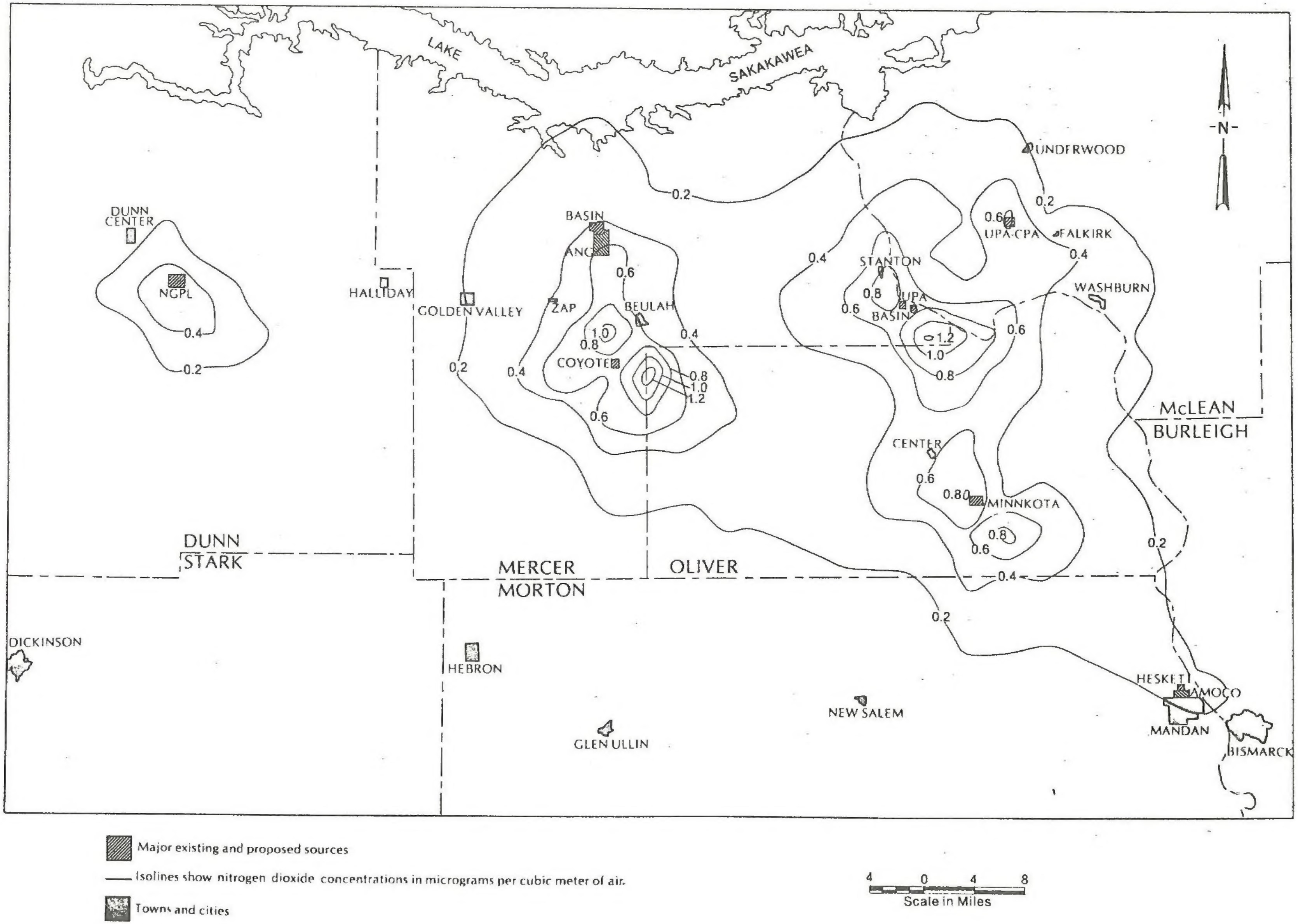
Nitrogen dioxide, as in the case of sulfur dioxide, is not expected to be emitted to the ambient air in measurable quantities as a result of proposed additional Level 2 area source developments. However, the proposed Coyote 2 electrical generating facility does constitute a nitrogen dioxide emission source within the scope of the additional Level 2 energy development proposals.

The air dispersion analysis performed for annual nitrogen dioxide emissions resulting from the proposed Coyote 2 electrical generating facility included the existing background and projected Level 1 development nitrogen dioxide air quality data and projected ground level concentration. The projected annual maximum ground level concentration for nitrogen dioxide is presented on Figure 38.

The annual projected maximum ground level concentration resulting from the proposed Coyote 2 electrical generating facility would be expected to be approximately 0.2 micrograms

Figure 38

PROJECTED ANNUAL CONCENTRATIONS OF NITROGEN DIOXIDE (NO_2) FROM ALL EXISTING AND PROPOSED SOURCES —LEVEL 2



SOURCE: North Dakota State Department of Health, 1977.

per cubic meter of air. The addition of the existing background nitrogen dioxide concentration to the Level 2 proposed development contributions would result in a total maximum projected annual ground level concentration of 5.76 micrograms per cubic meter of air in the seven county study area. The annual maximum allowable ambient air ground level concentration of nitrogen dioxide as established by State Ambient Air Quality Standards is 100 micrograms per cubic meter of air.

The short-term (1-hour) maximum projected ground level concentrations of nitrogen dioxide as a result of the proposed Coyote 2 electrical generating facility is presented in Table 41. The maximum 1-hour ground level concentration projected to occur is expected to be 203.1 micrograms per cubic meter of air. When this concentration, which includes the nitrogen dioxide contributions from the proposed Level 1 energy conversion facilities, is added to the existing background nitrogen dioxide concentration of 55 micrograms per cubic meter of air, the resulting maximum total projected nitrogen dioxide concentration in the seven county study area would be 258.1 micrograms per cubic meter of air.

Although this projected value is greater than 200 micrograms per cubic meter of air, it is only projected to occur 0.001% of the time on an annual basis (0.09 hours). This is less than the allowable 1% of the time in any 3-month period as allowed by the standard.

TABLE 41

SHORT TERM NITROGEN DIOXIDE ANALYSIS
Level 2 Proposed Projects

Atmospheric Stability Class 1/	Distance South of Coyote Boundary (miles)	Projected Concentrations 2/ 1-Hr ($\mu g/m^3$)	Background Concentrations 1-Hr ($\mu g/m^3$)	Total Concentrations 1-Hr ($\mu g/m^3$)
A	0.6	203.1	55.0	(258.1) 3/ 6/
B	1.5	90.4	55.0	(145.4)
C	1.8	132.5	55.0	(187.5)
D	6.8	90.4	55.0	(145.4)
E	35.8 4/	79.7	55.0	(134.7)
F 5/	--	--	--	--

SOURCE: North Dakota State Department of Health 1977

NOTE: All Oxides of Nitrogen emissions considered to be as Nitrogen Dioxide (NO_2).

1/ The stability class is a measure of the ability of the atmosphere to disperse emissions. Generally, Classes A, B, C, and D favor rapid dispersion whereas the more stable classes, E and F, are associated with poor dispersion.

2/ All concentrations are maximums for given stability class in micrograms per cubic meter of air. American Natural Gas concentrations based on normal operation conditions.

3/ Numbers in parenthesis have background added in and are to be compared to Ambient Air Quality Standards.

4/ This maximum concentration occurred with the wind from the south; therefore, ground level concentration is projected to occur north of the American Natural Gas, Basin site.

5/ The projected concentration under F Stability Class was found to be lower than those concentrations under E Stability Class for all cases. Also, the distance to the point of maximum concentration is so great that meteorological conditions are not likely to persist long enough for the plume to travel this far.

6/ The State Ambient Air Quality Standard is 200 micrograms per cubic meter of air ($\mu g/m^3$) maximum 1-hour concentrations, not to be exceeded over 1% of the time in any 3-month period. This concentration is projected to occur less than 0.001% of the time on an annual basis.

Reactive Sulfur (Sulfation)

Reactive sulfur (sulfation) is a measure of sulfur oxide compounds, sulfur dioxide, sulfur trioxide, and sulfuric acid in the ambient air. Sulfur trioxide and sulfuric acid are transformed in the ambient air from point source sulfur dioxide emissions, although a small amount of sulfur trioxide and sulfuric acid is also emitted directly.

Sulfur dioxide emissions to the ambient air in the seven county study area would result primarily from the proposed Level 1 point sources. These sources and their expected sulfur dioxide emissions in pounds per hour were presented in Tables 9, 10, and 11. It is expected that area sources involved in the Level 1 proposed developments would not contribute significant concentrations of sulfur dioxide and resulting reactive sulfur (sulfation) to the ambient air within the seven county study area.

The State Ambient Air Quality Standards for reactive sulfur (sulfation) are 0.25 milligrams of sulfur trioxide per one hundred square centimeters per day maximum annual arithmetic mean; and 0.50 milligrams of sulfur trioxide per one hundred square centimeters per day maximum for a one month period.

There are no existing emission standards or regulations for reactive sulfur (sulfation). Because reactive sulfur is directly related to sulfur dioxide, regulations for controlling sulfur dioxide emissions, which have been promulgated by both the state and federal governments, will also affect reactive sulfur.

The area source contributions of sulfur dioxide to the ambient air would be insignificant and would have a negligible impact on the environment within the seven county study area. This is also true for reactive sulfur since it is directly related to sulfur dioxide emissions.

The reactive sulfur (sulfation) ambient air contribution from the proposed additional Level 2 projects is expected to be negligible. As previously discussed, the additional Level 2 projects, with the exception of the proposed Coyote 2 electrical generating facility, constitute area sources and would not be expected to produce significant quantities of sulfur oxide compounds, measured as reactive sulfur, to the ambient air.

Other Air Contaminants

It is expected that the proposed projects in Level 1, would contribute increased carbon monoxide and hydrocarbon emissions to the ambient air. These emissions would primarily be the result of increased vehicle traffic, both on and off highways and roads, as well as heavy construction equipment, coal mining operations, and liquid hydrocarbon by-product recovery and storage at gasification plants.

Hydrocarbon emissions are regulated under the New Source Performance Standards promulgated by the Environmental Protection Agency and the State of North Dakota. These standards set requirements for the design and construction of storage vessels for petroleum liquids. In addition the state regulations require that waste gas streams containing hydrocarbon gases and vapors be burned by smokeless flares before emission to the ambient air.

In a study prepared for the U. S. Environmental Protection Agency, the projected increases in carbon monoxide and hydrocarbon ambient air concentrations would probably occur during heavy construction phases of Level 1 projects and subsequently decrease thereafter (PEDCo Environmental, Inc. 1976). It would, therefore, be anticipated that the ambient air levels of these two contaminants would not exceed the established permissible ambient air concentrations.

The concentration of photochemical oxidants in the ambient air within the seven county study area are expected to increase throughout the projected Level 1 development. Oxidants themselves are not emitted directly into the atmosphere, but are produced by a series of chemical reactions between nitrogen oxides and organic compounds including hydrocarbons in the presence of sunlight. The rate of oxidant formation is affected by the specific organic compounds present, the ratio of organic compounds to nitrogen oxides, and meteorological conditions such as solar intensity, temperature, and atmospheric stability.

Generally, peak concentrations are measured within a few hours of noon, although the emissions of organics and nitrogen oxides contributing to these peak concentrations may occur several hours earlier or remain from the previous day. Since the atmospheric photochemical reactions usually take several hours, the measured oxidant concentrations may occur many miles downwind from the points of emissions origin.

The probable sources of oxidants in the seven county study area and most other rural locations are downward transport from the ozone-rich layers of the stratosphere due to strong vertical mixing and the photochemical generation from organics emitted by vegetation. These natural sources of photochemical oxidants along with the secondary formation of oxidants from hydrocarbon and nitrogen oxide emissions are expected to constitute the primary sources of oxidants within the seven county study area. Since photochemical oxidants have not been a problem in North Dakota, they have not been given extensive sampling attention. Air sampling results to date are insufficient to define on existing levels of photochemical oxidants. Also, little emissions information exists with respect to hydrocarbons, photochemical oxidants, and other constituents from the proposed Level 1, Level 2 and Level 3 projects.

Another potential ambient air contaminant which may be contributed to the air environment of the seven county study area as a result of proposed Level 1 development is hydrogen sulfide. At the present time, there is no applicable Federal Ambient Air Quality Standard for hydrogen sulfide.

Only Level 1 coal gasification plants are expected to be the only additional sources of hydrogen sulfide to the ambient air. These proposed plants would be equipped with commercial sulfur recovery units which are expected to remove 98.5% of the sulfur, primarily hydrogen sulfide, from the plant effluent gases. Through a second process, a portion of the remaining hydrogen sulfide in the effluent streams is oxidized by incineration to sulfur dioxide. Since this process is not 100% efficient, a small quantity of hydrogen sulfide is expected to be contributed to the ambient air, however, the concentration should be within the existing state standards.

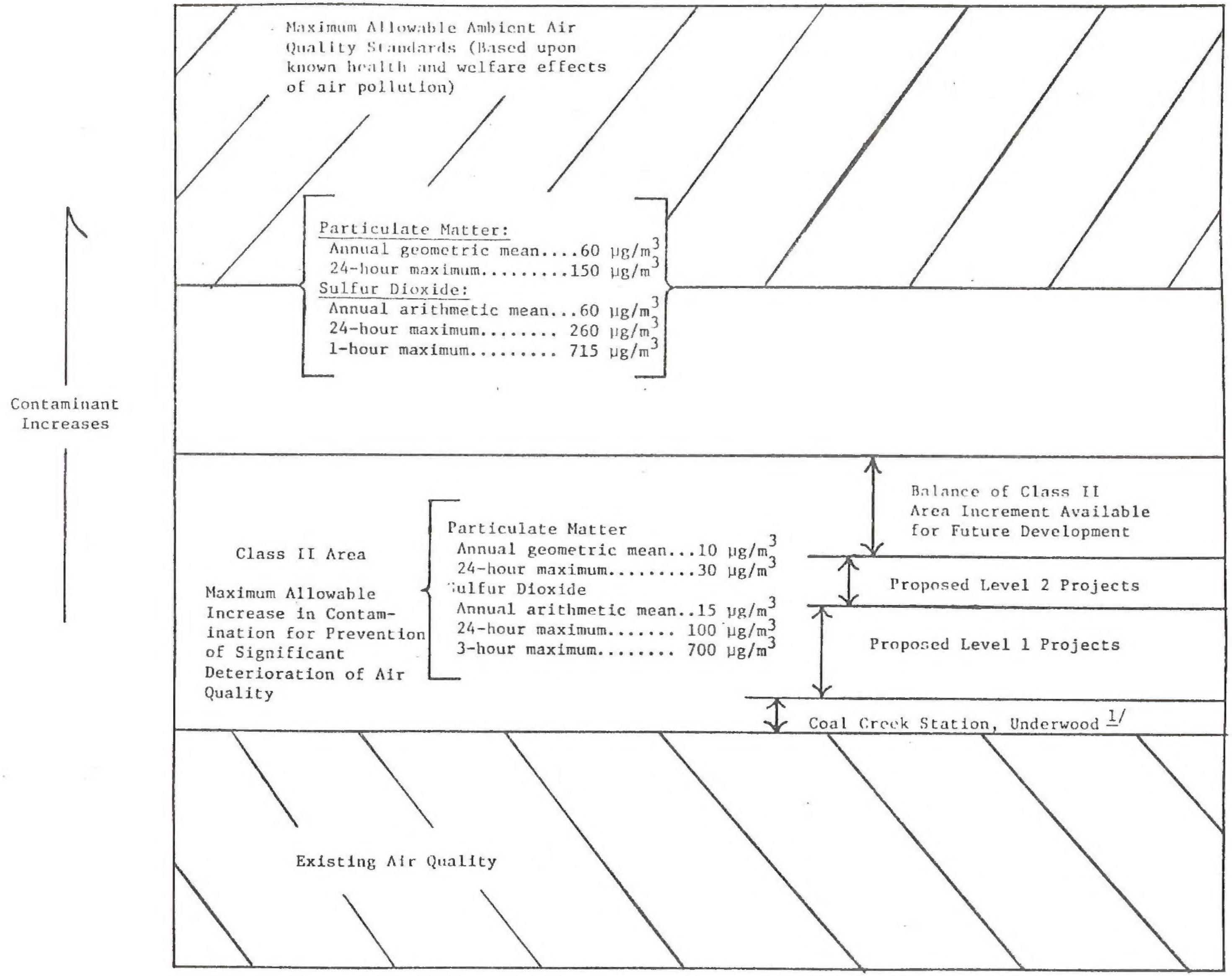
All Level 2 proposed projects are lignite coal mining operations with the exception of the proposed Coyote Station Unit 2. Coal mining operations do not constitute potential ambient air sources of hydrogen sulfide and therefore no impact from hydrogen sulfide on the environment would be expected to occur.

The addition of particulates into the atmosphere, either directly as suspended particulate emissions or indirectly as a result of chemical reactions of gaseous pollutants, may cause reduced visibility in small localized portions of the seven county study area. Total suspended particulate concentrations can be used to estimate visibility reduction, but the relationship at the present time is not well defined.

Air pollution control regulations will limit the amount and location of possible future Level 3 developments within the seven county study area. Future growth and development in this area will depend upon the ability of possible future projects, now known, to meet air pollution control regulations for preventing significant deterioration of air quality. These regulations establish an upper limit on the amount of increase above the existing air quality of the air contaminants, particulate matter and sulfur dioxide. This relationship is shown in Figure 39 for the Class II area allowable increment.

For purposes of analyzing the air quality impacts of possible future Level 3 developments, this discussion will be confined to a Class II area. Should areas within or near the seven county study area be reclassified from the present Class II area to the more limiting Class I area designation; possible future Level 3 development would be futher restricted. Depending upon the type, magnitude and location of possible future Level 3 projects; some or all of these projects may be excluded from the

FIGURE 39
PREVENTION OF SIGNIFICANT
DETERIORATION OF AIR QUALITY RELATIONSHIPS


Maximum Allowable Ambient Air Quality Standards (Based upon known health and welfare effects of air pollution)
Particulate Matter:
Annual geometric mean....60 μg/m3
24-hour maximum.........150 μg/m3
Sulfur Dioxide:
Annual arithmetic mean...60 μg/m3
24-hour maximum....... 260 μg/m3
1-hour maximum........ 715 μg/m3
Contaminant Increases
Class II Area
Maximum Allowable Increase in Contamination for Prevention of Significant Deterioration of Air Quality
Particulate Matter
Annual geometric mean...10 μg/m3
24-hour maximum.........30 μg/m3
Sulfur Dioxide
Annual arithmetic mean..15 μg/m3
24-hour maximum...... 100 μg/m3
3-hour maximum....... 700 μg/m3
Balance of Class II Area Increment Available for Future Development
Proposed Level 2 Projects
Proposed Level 1 Projects
Coal Creek Station, Underwood 1/
Existing Air Quality

SOURCE: North Dakota State Department of Health 1977

NOTE: Incremental relationships in this Figure are not to scale.

1/ Coal Creek Station, which is now under construction in the Underwood area is, by regulation, included in Prevention of Significant Deterioration of Air Quality Analyses.

seven county study area. This is illustrated in Figure 39. When the incremental increase allowed in a Class II area is used, no further development would be allowed. This illustration shows the step-wise filling of the increment by the addition of the United Power Association/Cooperative Power Association Coal Creek Station located near Underwood, and the proposed Level 1 and Level 2 projects to the existing air quality of the study area. The balance of the allowable increment is what is available for possible future Level 3 development. It should also be noted that the balance of Class II increment remaining could be used by industries other than those related to coal development such as in the oil and gas production areas of Dunn County. If non-coal type industries develop prior to coal-related, possible future Level 3 developments, less or perhaps no increment would be available for Level 3 development within the seven county study area.

Air quality analysis must of necessity be site specific with consideration of the specific industrial processes involved and location of such processes. These are unknowns with respect to possible future Level 3 developments. Further, as noted above, unpredicatable events including Class I area reclassification and non-coal related development prior to specific Level 3 proposed projects prevent an assessment of what is available for Level 3 development.

Referring to Figure 34, which shows the annual increase in sulfur dioxide across the seven county study area for all existing sources and proposed Level 1 and Level 2 projects could be inferred as describing where and how much annual increment is available for future development beyond proposed Level 2 projects. It would appear that over the entire seven county study area, at least 80% of the allowable 15 micrograms per cubic meter of air Class II area annual increment remains for possible future development. Annual averages as shown in Figure 34, while they must be considered for compliance with the air quality standards, cannot be used as the sole criteria in determining where and how much development is possible. This is evident by examination of Table 38, which presents the results of short-term sulfur dioxide analysis. Table 38 points out two important considerations, in addition to presenting information necessary to Level 2 project analysis. One, short-term averaging times are very dependent upon atmospheric stability which can vary widely, and two, the resulting concentrations are dependent upon knowing where the contaminant sources are located within the study area.

The reference point for the results of the short-term sulfur dioxide analysis is the Coyote boundary, to facilitate the predictive modeling for these results. At 0.6 miles from the Coyote boundary, the balance of Class II area increment remaining for future development beyond Level 2 projects is at least 67% in the case of the 3-hour averaging time and 10% in the case of the 24-hour averaging time when comparing the total predicted concentration to the appropriate Prevention of Significant Deterioration allowable increment. These maximum ground level concentrations of sulfur dioxide are predicted to occur under Class A atmospheric stability as a result of emissions from specific source interactions. Under another stability class, Class E for example, the balance of the increment available is 87% and 64%, respectively, for the 3-hour and 24-hour averaging times. This situation is predicted to occur 35.8 miles from the reference boundary.

This sulfur dioxide analysis includes all Level 1 and Level 2 proposed projects. Even with the site specific characteristics known for these projects, predicting the air quality effect interaction does not lend itself to a mapping display of the results due to the dependence upon variable meteorology and atmospheric stability for dispersion of point source emissions. Analysis of the short-term averaging times such as the 1-hour, 3-hour, and 24-hour must be approached from a maximum concentration standpoint, examining all conditions of atmospheric stability for compliance with the air quality standards. The acceptability of a proposed project is determined by the analysis of the dispersion of its emissions from a specific site and the resulting interaction with other specific sources which precede the proposed project.

The analysis of the air quality impacts and mitigation of impacts is not possible for Level 3 developments since the type, magnitude, location and other site specific characteristics of these possible future developments have not been defined. Long-range coal leasing decisions cannot be based upon air quality impacts without the knowledge of how the coal will subsequently be utilized, whether it be used in mine-mouth energy conversion facilities or for export. Individual possible future Level 3 projects, as they are defined, will be evaluated on a case-by-case basis in the step-wise addition to the Prevention of Significant Deterioration increment allowable. If sufficient increment is available, at that point in the future, possible future Level 3 projects would be allowed to proceed. Conversely, if the incremental balance is less than needed for Level 3 development, some or all of these developments may be prohibited. As shown above, analysis of short-term averaging time dispersion of site specific emissions will be the major determining criteria in the siting of future development projects as contrasted to the annual results which tend to average the influencing factor of meteorological dispersion. Only time and site specific analysis will resolve the question of possible future Level 3 development.

Projected Air Quality Effects Upon the Fort Berthold Indian Reservation from Potential Future Development

The potential effects upon the air quality of the Fort Berthold Indian Reservation were evaluated in the course of this study since a portion of the reservation lies within the boundaries of northern and western Dunn, Mercer, and McLean Counties.

The dispersion analysis for particulates, sulfur dioxide, and nitrogen dioxide annual maximum projected concentrations have been presented on Figure 29, Figure 33, and Figure 37, respectively, for the proposed Level 1 developments. Even though the total area of the Fort Berthold Indian Reservation is not shown on these maps, the greater the distance from the emission source, the lower the resulting projected ground level concentrations would be for any air contaminant.

Figure 29, presenting the projected annual total suspended particulate ground level concentrations in the seven county study area resulting from proposed Level 1 developments, indicates projected annual particulate concentrations, in the area of the Fort Berthold Indian Reservation, to be less than 0.6 micrograms per cubic meter of air. The addition of the projected 0.6 microgram per cubic meter of air ground level concentration in the Fort Berthold Indian Reservation area to the 25 micrograms per cubic meter of air annual background concentration would be negligible. Therefore, the contribution of particulates from the proposed Level 1 developments would have a minor effect on the existing air quality on the Fort Berthold Indian Reservation.

Figure 30, presenting the projected annual suspended particulate ground level concentrations in the seven county study area resulting from proposed additional Level 2 developments indicates projected annual particulate concentrations in the area of the Fort Berthold Indian Reservation to be less than 0.6 micrograms per cubic meter of air. The addition of the projected 0.6 microgram per cubic meter of air ground level concentration in the Fort Berthold Indian Reservation area to the 25 micrograms per cubic meter of air annual background concentration would be negligible. Therefore, the contribution of particulates from the proposed additional Level 2 developments would not be expected to affect the existing air quality on the Fort Berthold Indian Reservation.

For comparison of the projected maximum particulate ground level concentrations of the Federal Ambient Air Quality Standards, the concentration is added to the existing measured 24-hour background value of 80 micrograms per cubic meter of air. The resulting value of slightly more than 80 micrograms per cubic meter of air which is essentially the existing background concentration, is less than the maximum allowable 24-hour Secondary Federal Ambient Air Quality Standard for particulates of 150 micrograms per cubic meter of air. From this analysis, no adverse short-term impacts to the air quality would be expected to occur within Fort Berthold boundaries from particulate emissions resulting from the proposed additional Level 2 development.

As previously discussed, Figure 33 presented the projected annual maximum ground level concentrations for sulfur dioxide in the seven county study area. From a review of this map, it can be observed that the projected ground level concentrations of sulfur dioxide resulting from Level 1 proposed development would be expected to add less than 1 microgram per cubic meter of air in the area of the Fort Berthold Indian Reservation, to the annual background sulfur dioxide concentration of 5 micrograms per cubic meter of air. This additional ambient air quality concentration of sulfur dioxide within the boundaries of the Fort Berthold Indian Reservation would be minor.

Figure 34 presented the projected annual maximum ground level concentration for sulfur dioxide resulting from proposed Level 2 development in the study area. The projected annual ground level concentration of sulfur dioxide resulting from additional Level 2 proposed development would be expected to add less than 1 microgram per cubic meter of air to the annual background sulfur dioxide concentration of 5 micrograms per cubic meter of air. This additional ambient air quality concentration of sulfur dioxide within the boundaries of Fort Berthold would be unmeasurable.

Projected short-term (3-hour and 24-hour) maximum ground level concentrations usually occur in the immediate vicinity of air contaminant emission sources such as the proposed Level 1 developments. The distance from an emission source where maximum short-term ground level concentrations of an air contaminant may occur is dependent upon meteorological conditions such as wind speed, temperature, and atmospheric stability. Under meteorological conditions which give rise to long-range air contaminant transport, some influence upon the air quality within the Fort Berthold Indian Reservation would be expected in the short-term. This influence is compared to the established Federal Ambient Air Quality Standards and the existing Federal Prevention of Significant Deterioration of Air Quality Regulations for a Class II area only, since the State of North Dakota does not have jurisdiction over Indian reservations.

Table 42 summarizes the projected maximum short-term particulate and sulfur dioxide concentration contribution upon the existing air quality within the Fort Berthold Indian Reservation from Level 1 proposals. As presented in the table, the maximum short-term (24-hour) projected ground level particulate concentration occurring within Fort Berthold boundaries is 2 micrograms per cubic meter of air as a result of proposed Level 1 development. A comparison of this projected maximum short-term ground level concentration to the Federal 24-hour Prevention of Significant Deterioration of Air Quality Regulations for a Class II area of 30 micrograms per cubic meter of air increment shows that proposed Level 1 developments outside of Fort Berthold would not significantly impact the air quality increment established for Fort Berthold. For comparison

TABLE 42

PROJECTED MAXIMUM SHORT TERM AIR CONTAMINANT IMPACTS UPON FORT BERTHOLD RESERVATION
Level 1 Projects

	Total Suspended Particulate (micrograms per cubic meter of air)			Sulfur Dioxide (micrograms per cubic meter of air)					
	Projected Concentration 24-Hr	Background Concentration 24-Hr	Total Concentration 24-Hr	Projected Concentration 3-Hr	Projected Concentration 24-Hr	Background Concentration 3-Hr	Background Concentration 24-Hr	Total Concentration 3-Hr	Total Concentration 24-Hr
	2	80	2 (82)1/	84.9	34.0	35	25	84.9 (120.)	24.0 (59.0)
Standards			302/ 1503/					7002/ 13003/	1002/ 3655/

SOURCE: North Dakota State Department of Health 1977

NOTE: The maximum ground level concentration was projected to occur at the southern boundary of the Fort Berthold Indian Reservation. The distance from this boundary to the north boundary of the Basin Electric Complex is eight miles.

1/ Numbers in parenthesis have background added in and are to be compared to Ambient Air Quality Standards. Numbers without parenthesis are counted against Prevention of Significant Deterioration of Air Quality increments.

2/ Prevention of Significant Deterioration of Air Quality increments (Class II).

3/ Maximum allowable concentrations for Federal Secondary (most stringent) Ambient Air Quality Standards.

4/ Maximum allowable concentrations for Federal Primary Ambient Air Quality Standard.

of the projected maximum particulate ground level concentrations to the Federal Ambient Air Quality Standards, the concentration of 2 micrograms per cubic meter of air is added to the existing measured 24-hour background value of 80 micrograms per cubic meter of air. The resulting value of 82 micrograms per cubic meter of air is less than the maximum allowable 24-hour secondary Federal Ambient Air Quality Standard for particulates of 150 micrograms per cubic meter of air.

The projected short-term (3-hour and 24-hour) maximum ground level concentrations for sulfur dioxide occurring within the Fort Berthold Indian Reservation boundaries are 84.9 micrograms per cubic meter of air and 34.0 micrograms per cubic meter of air for the 3-hour and 24-hour averaging time periods respectively as a result of the proposed Level 1 developments. The 3-hour projected maximum ground level concentration of sulfur dioxide constitutes 12% of the allowable Federal 3-hour Prevention of Significant Deterioration of Air Quality increment of 700 micrograms per cubic meter of air. The 24-hour projected maximum ground level concentration of sulfur dioxide would be 34% of the allowable Federal 24-hour Prevention of Significant Deterioration of Air Quality Regulation increment of 100 micrograms per cubic meter of air. From this analysis it would appear that the influence of the proposed Level 1 development occurring outside of the Fort Berthold Indian Reservation boundaries would not impact the established Federal Prevention of Significant Deterioration of Air Quality increment for sulfur dioxide to an extent which would restrict potential future industrial development of Fort Berthold.

The addition of the existing 3-hour and 24-hour background concentrations for sulfur dioxide in the seven county study area to the maximum 3-hour and 24-hour projected ground level concentrations yield values of 120 micrograms per cubic meter of air and 59 micrograms per cubic meter of air, respectively. The 120 micrograms per cubic meter of air concentration is less than the maximum allowable 3-hour Federal Secondary Ambient Air Quality Standard of 1300 micrograms per cubic meter of air. The 59 micrograms per cubic meter of air concentration is within the maximum allowable 24-hour Federal Primary Ambient Air Quality Standard of 365 micrograms per cubic meter of air.

Table 43 summarizes the projected short-term particulate and sulfur dioxide concentration contribution upon the existing air quality within the Fort Berthold Indian Reservation from proposed Level 2 development. As presented in the table, the maximum short-term (24-hour) projected ground level particulate concentrations occurring within Fort Berthold would be less than 1 microgram per cubic meter of air as a result of proposed Level 2 development.

The projected short-term (3-hour and 24-hour) maximum ground level concentrations for sulfur dioxide occurring within Fort Berthold boundaries are 92.9 micrograms per cubic meter of air

TABLE 43

PROJECTED SHORT TERM AIR CONTAMINANT IMPACTS UPON FORT BERTHOLD RESERVATION
Level 2 Projects

Total Suspended Particulate (micrograms per cubic meter of air)			Sulfur Dioxide (micrograms per cubic meter of air)					
Projected Concentration[1] 24-Hr	Background Concentration 24-Hr	Total Concentration[1] 24-Hr	Projected Concentration		Background Concentration		Total Concentration	
			3-Hr	24-Hr	3-Hr	24-Hr	3-Hr	24-Hr
less than 1	80	less than 1	92.9	37.2	35	25	92.9 (127.9)[2]	37.2 (62.2)
Standards		30[3] 150[4]					700[3] 1300[4]	100[3] 365[5]

SOURCE: North Dakota State Department of Health 1977

NOTE: The maximum ground level concentration was projected to occur at the southern boundary of the Fort Berthold Indian Reservation. The distance from this boundary to the north boundary of the Basin Electric Complex is eight miles.

1/ The short term ground level concentrations projected to occur on the Forth Berthold Indian Reservation resulting from the projected Level 2 projects were so slight they were considered negligible. (less than 1 μg/m^3)

2/ Numbers in parenthesis have background added in and are to be compared to Ambient Air Quality Standards. Numbers without parenthesis are counted against Prevention of Significant Deterioration of Air Quality increments.

3/ Prevention of Significant Deterioration of Air Quality increments (Class II).

4/ Maximum allowable concentrations for Federal Secondary (most stringent) Ambient Air Quality Standards.

5/ Maximum allowable concentrations for Federal Primary Ambient Air Quality Standards.

and 37.2 micrograms per cubic meter of air, respectively, as a result of the proposed Level 2 developments. The 3-hour projected maximum ground level concentration of sulfur dioxide constitutes 13% of the allowable Federal 3-hour Prevention of Significant Deterioration of Air Quality increment of 700 micrograms per cubic meter of air for a Class II area. The 24-hour projected maximum ground level concentration of sulfur dioxide would be 37% of the allowable Federal 24-hour Prevention of Significant Deterioration of Air Quality Regulation increment of 100 micrograms per cubic meter of air for a Class II area. From this analysis it would appear that the influence of the proposed additional Level 2 development occurring outside of the Fort Berthold boundaries would not impact the established Federal Prevention of Significant Deterioration of Air Quality increment for sulfur dioxide to an extent that would restrict potential future industrial development on Fort Berthold.

The addition of the existing 3-hour and 24-hour background concentrations for sulfur dioxide in the seven county study area to the maximum 3-hour and 24-hour projected ground level concentrations yields values of 127.9 micrograms per cubic meter of air and 62.2 micrograms per cubic meter of air, respectively. The 127.9 micrograms per cubic meter of air concentration is less than the maximum allowable 3-hour Federal Secondary Ambient Air Quality Standard of 1300 micrograms per cubic meter of air. The 62.2 micrograms per cubic meter of air concentration is less than the maximum allowable Federal Primary Ambient Air Quality

Standard of 365 micrograms per cubic meter of air. On the basis of this comparison, no short-term adverse impacts upon the ambient air quality from sulfur dioxide emissions would be expected to occur within Fort Berthold boundaries as a result of the proposed additional Level 2 developments.

A comparison of the projected maximum short-term ground level concentration to the Federal 24-hour Prevention of Significant Deterioration of Air Quality Regulations for a Class II area of 30 micrograms per cubic meter of air increment indicates that proposed additional Level 2 developments outside of Fort Berthold would not impact the air quality increment established for the Reservation.

Figure 37, presented the projected annual maximum ground level concentrations for nitrogen dioxide in the seven county study area resulting from the proposed Level 1 developments. The projected ground level concentration of nitrogen dioxide in the Fort Berthold Indian Reservation area is less than 0.5 microgram per cubic meter of air. The addition of this projected ground level concentration to the existing annual background level of 5 micrograms per cubic meter of air would not be measurable with current air quality monitoring technology.

Figure 38, presented the projected annual maximum ground level concentrations for nitrogen dioxide in the seven county study area resulting from the proposed additional Level 2 developments. The projected ground level concentration of nitrogen dioxide in the Fort Berthold Indian Reservation area is less than 0.5 microgram per cubic meter of air. The addition of this projected ground level concentration to the existing annual background level of 5 micrograms per cubic meter of air would be unmeasurable. All of the projected annual ground level concentrations for particulates, sulfur dioxide, and nitrogen dioxide are less than the Federal Primary and Secondary Ambient Air Quality Standards. On the basis of this analysis, no adverse environmental impacts to the air quality on Fort Berthold would be expected to occur as a result of the proposed additional Level 2 developments. North Dakota Air Pollution Control Regulations do not apply on Indian reservations.

All other air contaminants discussed within the seven county study area Level 1 analysis would not be expected to be of sufficient ground level concentrations to cause adverse environmental impacts. The actual projected concentrations of the various other air contaminant components such as hydrocarbons and photochemical oxidants cannot be formulated since current state of the art air dispersion modeling techniques do not exist for these contaminants.

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TRACE ELEMENT EFFECTS OF ENERGY CONVERSION FACILITIES

TRACE ELEMENT EFFECTS OF ENERGY CONVERSION FACILITIES:

A Phase One Final Report to the Old West Regional Commission

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ABSTRACT

This study was performed in a 2400 square mile area of western North Dakota to evaluate the potential significance of 15 trace elements (As, Be, Cd, Cr, Cu, F, Pb, Hg, Mo, Ni, Se, S, U, V, Zn) released to the environment through the energy conversion of coal. The methodology for evaluating these trace elements included the analysis of coal from four coal mines; the study of operating histories and design parameters of six lignite-fired electrical generating facilities; and the analysis of soil taken from 205 locations within the study area.

The concentration of trace elements in the coal and facility design parameters served as input data for a climatological dispersion model with a deposition function for estimating the dry deposition of trace elements to the study area. Trace element deposition was compared to existing soil concentrations. The application of a climatological dispersion-deposition model demonstrated that modern era energy conversion facilities contribute three orders of magnitude less surface deposition than do energy conversion facilities designed and operated since the 1920's.

This report presents a methodology for determining the significance of individual trace elements released to the environment through the energy conversion of coal. For short-

term (annual projections), the projected depositions on environmental receptors are not expected to cause adverse effects on ecosystems. However, equating the potential long-term environmental significance of the quantities of these trace elements deposited to the environment remains for further evaluation as part of this continuing research effort being conducted in cooperation with the Old West Regional Commission.

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INTRODUCTION

Background

The conversion of energy, from a stored or potential source in nature, to a useable form has been and will continue to be a challenge to man in meeting "supply-demand" requirements. The availability of energy is necessary to the sustaining of the nation's posture in the world. An abundant supply of energy represents, in the world economy, a major factor for future growth and development in an ever-increasing technological society. One need only to examine the increasing dependence that has been placed upon energy availability in recent years.

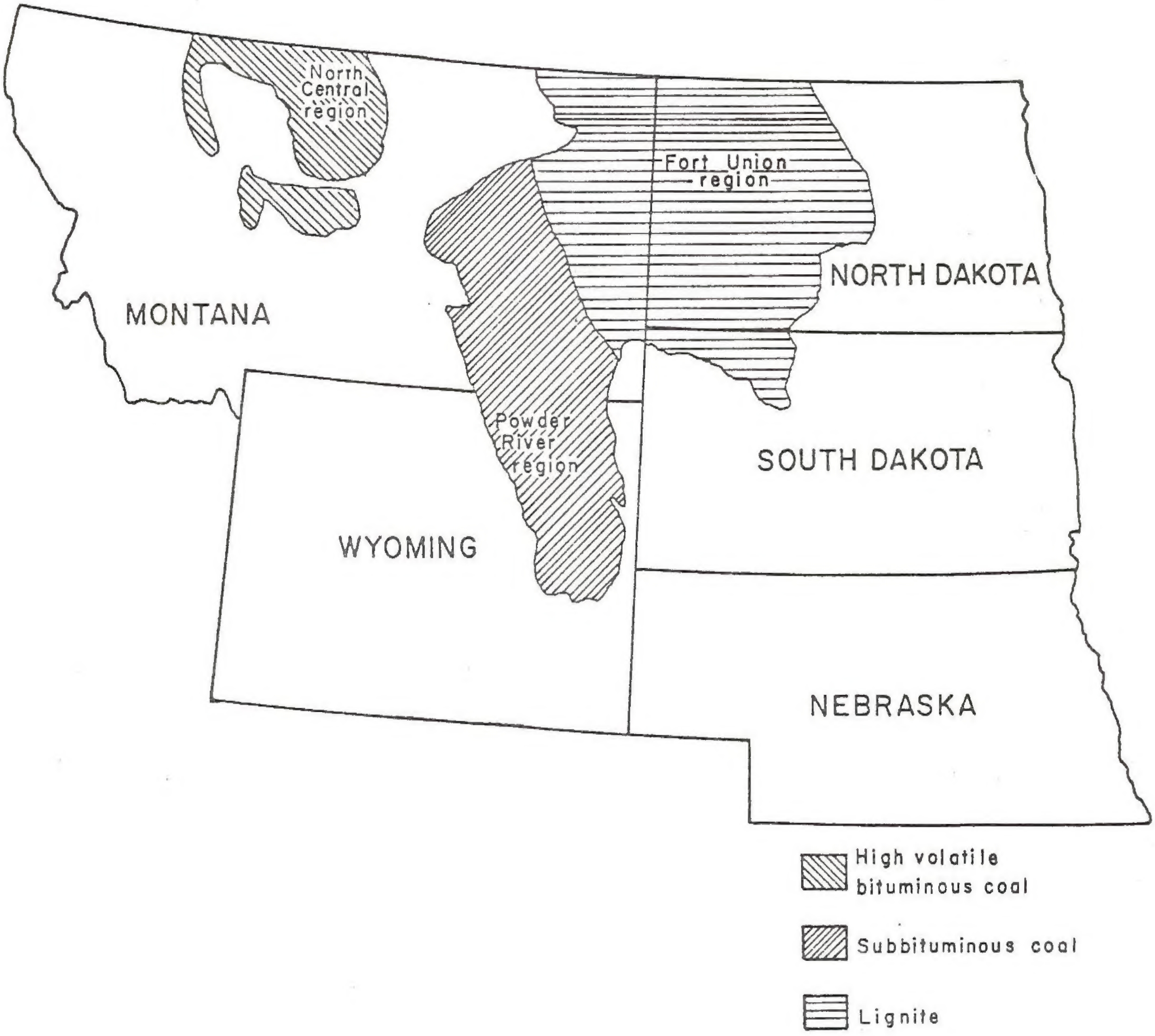
In the United States today, there are various predictions concerning reserves of oil and natural gas. While these predictions vary, there appears to be agreement that the supply of domestic oil and natural gas is limited and may not be able to meet increasing demands, or needs, for energy in the future. In addition, the dependence upon other countries "rich in energy" does not appear to be an acceptable alternative to maintaining an adequate supply of fossil fuels. Attention has been directed to the development and utilization of coal in the energy conversion process. Although other types of energy conversion processes, for example nuclear and solar, are being considered more aggressively; it appears that a fossil-fueled energy supply will continue to be the primary source of energy, with greater emphasis placed on the utilization of coal.

Development and utilization of coal reserves of this region is underway, with even more significant utilization projected. The "mine-mouth" production of coal for electrical generation and the conversion of coal to synthetic fuels pose environmental questions specifically for the states of Montana, Wyoming, and North Dakota. The significance of these environmental questions is emphasized by the expanse of coal reserves which are or could potentially be utilized within these states as shown in Figure 1. The environmental questions of coal utilization are not unique to these three Old West Region states since the states of South Dakota and Nebraska will, no doubt, be using some of the coal exported from the other three states richer in coal deposits. An example of this export-import relationship is the transportation of coal from southwestern North Dakota to a power generating station in northeastern South Dakota. It does appear that environmental questions will be regional in scope. Further, distribution of airborne contaminants is not restricted by geographical boundaries.

Much of the attention of the environmental impact of coal resource development has been concentrated on the more conventional, or historic effects of environmental contamination. The emphasis has been on the direct effects of contaminants such as particulates and sulfur dioxide. Little attention has been devoted to the effect of trace element translocation and enrichment in the environment of living organisms.

FIGURE 1

COAL PRODUCTION AREAS OF THE OLD WEST REGION



SOURCE: Federal Energy Administration 1975

Considerable chemical and physical analysis has been performed on the coals of this region, with emphasis on the assessment of the energy potential of coal. Analytical tests on coal have been largely confined to determination of the chemical composition, physical properties, and behavior of coals as they relate to the combustion process. These tests include the proximate analysis (volatile matter, fixed carbon, ash, sulfur, BTU/lb., and moisture content) and the ultimate analysis (chemical elements - including hydrogen, carbon, sulfur, oxygen, nitrogen, ash and moisture). Other typical analyses include: friability, grindability, screen sizing, free swelling and ash fusibility of the coal.

Coal contains other chemical elements in varying "trace" concentrations. It is toward these trace concentrations that this study is directed. Trace elements can generally be defined as those elements present in materials in concentrations of 1,000 parts per million (ppm) or less. Although these elements are called "trace elements" they may be as important to the energy development question as the energy potential of the coal itself. Any chemical element, when released into the environment becomes a part of the environment; and due to the chemical properties of the particular element considered, it tends to move within the environmental food chains of living organisms.

Trace elements are found throughout the environment. Soil, for example, is a mixture of "natural" trace elements which, in the agricultural setting, are utilized in the production of food and fiber. Increases in the concentration of the natural chemical elements in the soil, through contamination, has resulted in deleterious effects (Bauchauer, 1973; Churchill et al., 1948; Dunn et al., 1932; Hammond and Aronson, 1964). The deleterious effects are a function of the specific trace element concentrations, both natural and enriched; and the duration of the contaminating event.

As a result of recent interest in trace elements, these chemical elements have generated fears concerning future energy development. These fears exist even though some of these elements are essential for proper nutritional-biological functioning, i.e., essential for health and life. In the case of animal health, for example, this group of essential elements includes chromium, cobalt, copper, iodine, iron, manganese, molybdenum, selenium, and zinc (Frieden, 1972). Deficiencies of essential trace elements have occurred when the nutritional availability of trace elements has changed. Excessive concentrations of some elements have been demonstrated to interfere with the normal availability of the essential trace elements, thereby creating a deficiency condition. It is necessary, therefore, that the trace element effects of energy conversion facilities be examined for assessment of environmental impact.

Energy Development

Energy development activities are projected to increase markedly within the states of this region. The Northern Great Plains Resources Program, 1974, (NGPRP) considered the question of the magnitude of coal development in this region. Three levels of development were addressed by the NGPRP: Base, Most Probable, and Extensive. Excerpts from the Most Probable projections are presented in Tables 1, 2, and 3. Examination of these tables yields a numerical projection of future coal utilization. From Table 1, the Most Probable regional installed electrical generating capacity increase would be on the order of four to ten times existing (1974 base) capacities by the years 1985 and 2000, respectively. Increases in generating capacity means greater coal utilization, even when considering improvements in the thermal efficiency of future generating stations. Increase of coal utilization subsequently results in increased emission of process wastes, even when best available control technology is applied.

With respect to the production of synthetic natural gas from coal, the NGPRP has projected, from Table 2, that the most probable regional gasification capacity would be 1750 and 4000 million standard cubic feet of gas per day (MMSCFD) for the years 1985 and 2000, respectively. The nominal gasification plant size, under design consideration today, is 250 MMSCFD; this means that the number of plants projected for 1985 and 2000 are 7 and 16, respectively. In Table 3, these plant numbers are

TABLE 1

PROJECTED INSTALLED ELECTRICAL GENERATING CAPACITY

State	Installed Capacity in Megawatts Existing January 1974	Most Probable 1985	Most Probable 2000
Montana	345	3101	9100
Nebraska	1534	3670	6920
North Dakota	862	4125	14910
South Dakota	252	1504	6060
Wyoming	1535	3893	8455
Regional Total	4528	16293	45445

SOURCE: Northern Great Plains Resources Program
Atmospheric Aspects Work Group Report
December 1974

TABLE 2

ESTIMATED GASIFICATION CAPACITY

State	Estimated Gasification Capacity (MMSCFD) Existing January 1974	Most Probable 1985	Most Probable 2000
Montana	0	750	1500
North Dakota	0	500	1750
Wyoming	0	500	750
Regional Total	0	1750	4000

SOURCE: Northern Great Plains Resource Program
Atmospheric Aspects Work Group Report
December 1974

TABLE 3

GASIFICATION DEVELOPMENT FORECAST

State (Most Probable)	1985 Number of Plants	 Coal[1/] Requirement	2000 Number of Plants	 Coal Requirement
Montana	3	22.2	6	46.3
North Dakota	2	20.1	7	69.7
Wyoming	2	15.5	3	24.2

[1/] Million tons per year.

SOURCE: Northern Great Plains Resources Program
Atmospheric Aspects Work Group Report
December 1974

translated into projected coal requirements. The apparent variability of the total coal requirements per plant, as indicated from Table 3, is due to the type and quality of coal available.

Currently, there is no commercial gasification operation in the United States. The coal gasification industry would not only be a new industry to the Old West Region, but it would be new to the United States as well. The production of other synthetic fuels from coal, such as synthetic petroleum via the liquefaction process, is in various stages of research and development; however, this process has not progressed as rapidly as the synthetic natural gas process. It is also possible, in the years ahead, to see the coals of this region being utilized as a feed stock in the chemical industry, in addition production of synthetic fuels.

Environmental Protection

Coal conversion in this region, whether it be electrical energy from coal-fired generating stations or synthetic fuels and chemicals from gasification facilities represents a significant increase in the amount of coal utilized. As pointed out earlier, the utilization of coal in these energy conversion processes will result in increased emission of process wastes, even when the best available control technology is applied. In addition to the question of increases in total waste emissions, other environmental factors must be considered. Other environmental factors including the location and density of energy conversion facilities within the respective states. Questions, such as how much development, where to site such developments, and the type and degree of control over environmental emissions from developments; are questions which must be carefully considered and resolved. To facilitate the "proper" decision-making process, "best judgment" must be applied. Obviously, the fewer the unknowns, the better the judgment.

From the air pollution standpoint, traditional contaminants produced by coal utilization processes, such as particulates and sulfur dioxide, have been studied at considerable length. Control mechanisms, emission limitations, and ambient air quality standards exist for these contaminants in all states of this region. Control technology, when combined with proper facility siting, can be effective in preventing the adverse environmental aspects associated with these contaminants. Emission limitations and/or ambient standards are all but non-existent with respect to specific trace elements.

Although it is possible to have a direct trace element effect on living organisms from either an acute or chronic exposure to these contaminants (similar to that of the particulate or sulfur dioxide contaminants), trace elements can also cause an indirect effect via their translocation in the ecosystem food chain of living organisms.

It would appear that trace element decisions to this point in time, have been generally based upon case histories, isolated incidents, or unsupported assumptions that trace elements will be of little significance. Study of the trace element concentrations involved with coal development and the effect of these concentrations on living organisms must be addressed to eliminate fears, where fears are not warranted; and/or to evaluate more thoroughly the controls which will have to be applied to trace element emissions presenting potential problems. Some of the trace elements in coal will not be of significant concentration or specific chemical form to be of concern. The potential trace element effects will be a function of the concentration, chemical properties, and the mechanism of control of waste discharges to the environment.

There is a need, within this region, to evaluate emission control limitations and environmental quality standards for trace elements. Of the states in this region, only Montana and Wyoming have established numerical ambient air quality standards for air contaminants which could be classified as trace elements. These are: lead, beryllium, and hydrogen fluoride, in the case of Montana; and hydrogen fluoride in the case of Wyoming. In the North Dakota Ambient Air Quality Standards, the limiting of potential effects from trace elements is covered in general terms, with the following language:

> *"The ambient air shall not contain air contaminants in concentrations that would be injurious to human health or well-being or unreasonably interfere with the enjoyment of property or that would injure plant or animal life."*

This statement does not specifically address trace elements in terms of chemical contaminants, nor is an assigned "standard" concentration established. Further, the implementation of a general standard such as this, is based upon "after-the-fact" problems, rather than a more desirable preventative standard.

Scope of this Study

The decision-making process involved in the review and evaluation of a proposed energy conversion facility is site specific. The decision concerning a proposed project, from the environmental standpoint must be based upon the type coal utilization process proposed, the specific characteristics of the coal used, the environmental controls exercised and final disposition of waste discharges. These site specific variables preclude the direct application of the results of this study to individual localized situations. Each "site specific" decision will have to be made on its own merits. This study proposes to remove unknowns from, and to provide a factual mechanism for, the decision-making process as it relates to potential effects of trace elements on living organisms. In this world of probabilities, there are few human decisions which are based upon absolutes. Removal of unknowns, however, will enhance the decision-making process while reducing the risks associated with such decisions.

Considerable research information on trace elements is available in the literature as demonstrated in the Appendices of this report. Much of this information, although useful, cannot be directly utilized in the decision-making process. The information in the literature crosses many technical and scientific disciplines. There is no unifying of this information into one single systematic utilization of basic and applied research to the point of assessing the potential effects of environmental trace elements from coal development.

Resources limited resolution of all questions related to the effects of trace elements from energy conversion facilities. This study was designed to build upon the existing data and research base; to acquire additional detailed trace element data; to analyze the potential for environmental enrichment of the trace elements; and, to determine the potential trace element effects of coal development. The trace elements under consideration in this study include: arsenic, beryllium, cadmium, chromium, copper, fluoride, lead, mercury, molybdenum, nickel, selenium, sulfur, uranium, vanadium, and zinc.

Study Objectives

The objectives of this study focus on determining the effects of trace elements environmentally redistributed through the energy conversion process. These objectives will enable the states of this region to plan for, regulate and otherwise prevent adverse environmental impacts on our citizens and the agricultural communities of the respective states. Regardless of the type coal-to-energy conversion process, trace elements pose a number of questions related to both short and long-term effects. To this end, the specific objectives of this study are:

1. to identify potential-problem trace elements in coal,

2. to determine the trace element profile of soils,

3. to determine the rate and concentration buildup of trace elements in the soil reservoir from existing coal-fired power plants,

4. to determine, via modeling of air emissions of trace elements, projected soil reservoir buildup of trace elements; and

5. to examine the need for development of specialized control procedures and/or regulatory control procedures for trace element wastes from energy conversion facilities.

METHODS

An environmental laboratory of approximately 2,400 square miles in western North Dakota was employed to evaluate trace element translocation from energy conversion facilities. Characterized by a gently rolling topography, typical of the northern Great Plains; this area is desirable since there are no industrial or large population sources other than those related to the energy conversion facilities involved in this study. Figure 2 shows the geographical relationship of the study area to the State of North Dakota. All of the aspects of an evaluation of trace element emissions from energy conversion facilities, as shown in Figure 3, exist in this area. The lignite coal-fired thermoelectric generating stations located in the area allow the study of effects in both a historical as well as potential sense.

The scope of this study focused on two localized areas, Area A and Area B, each twenty miles in diameter, as shown in Figure 4. Field work consisted of the collection of coal and soil samples in these areas. The surrounding area, Area C, was also sampled. However, study funds limited extensive soil analysis. The samples were analyzed for fifteen specific trace elements.

The study of airborne translocation involved the analysis of the operating history as well as the current environmentally-related operations of lignite coal-fired power plants located in the

FIGURE 2

GENERAL TRACE ELEMENT STUDY AREA

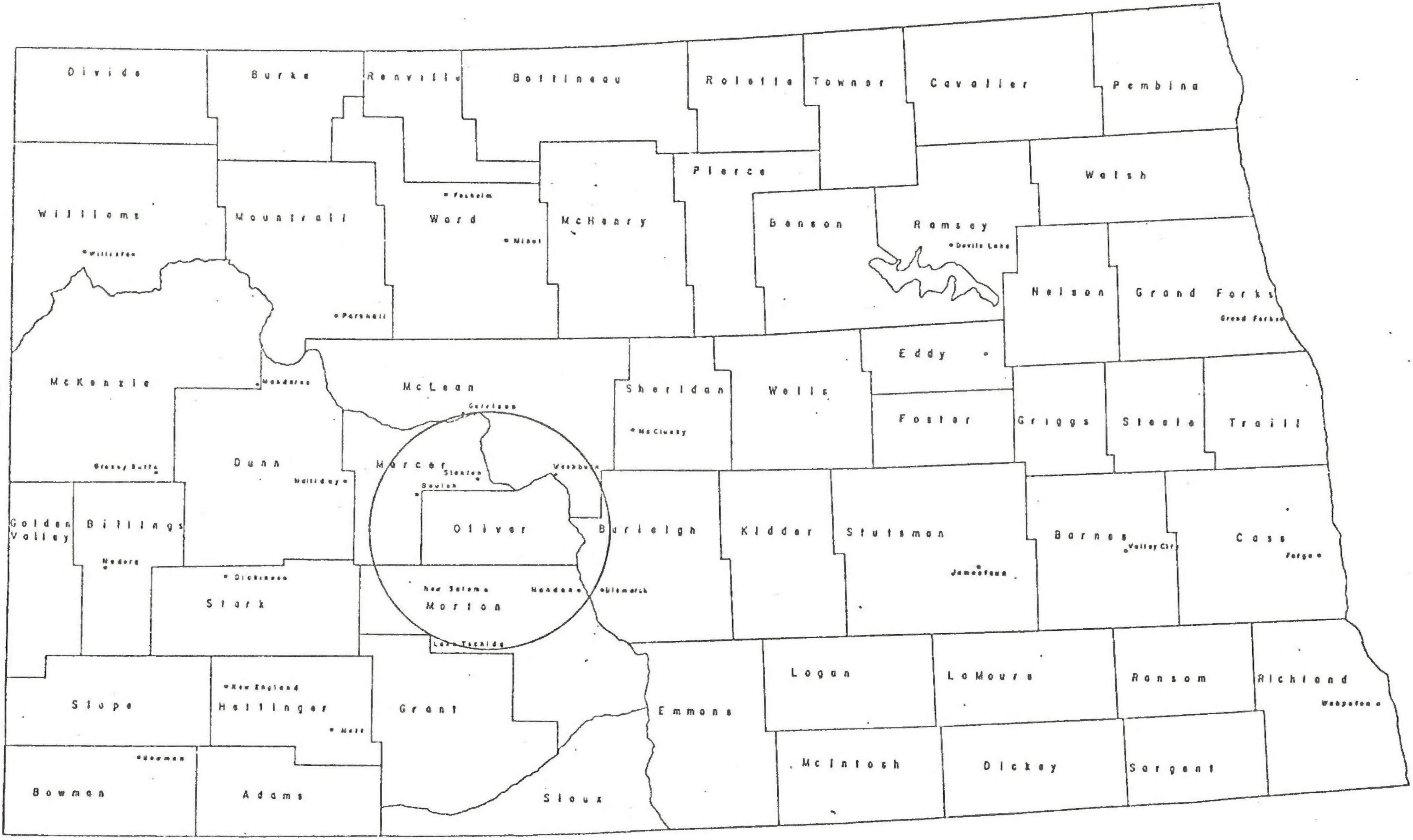


FIGURE 3

TRANSLOCATION OF TRACE ELEMENTS

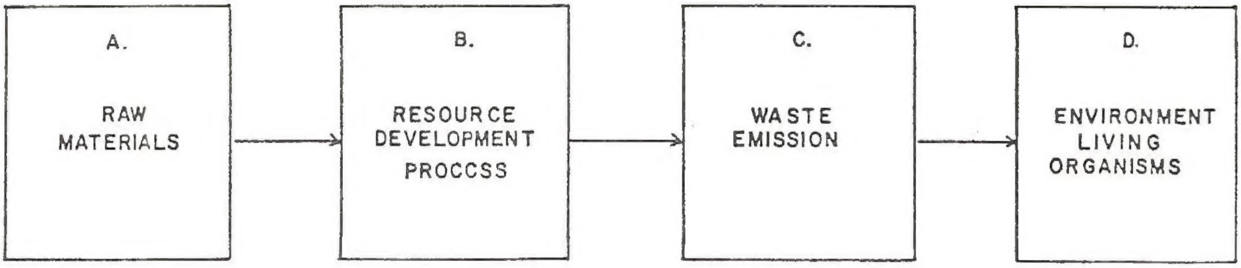
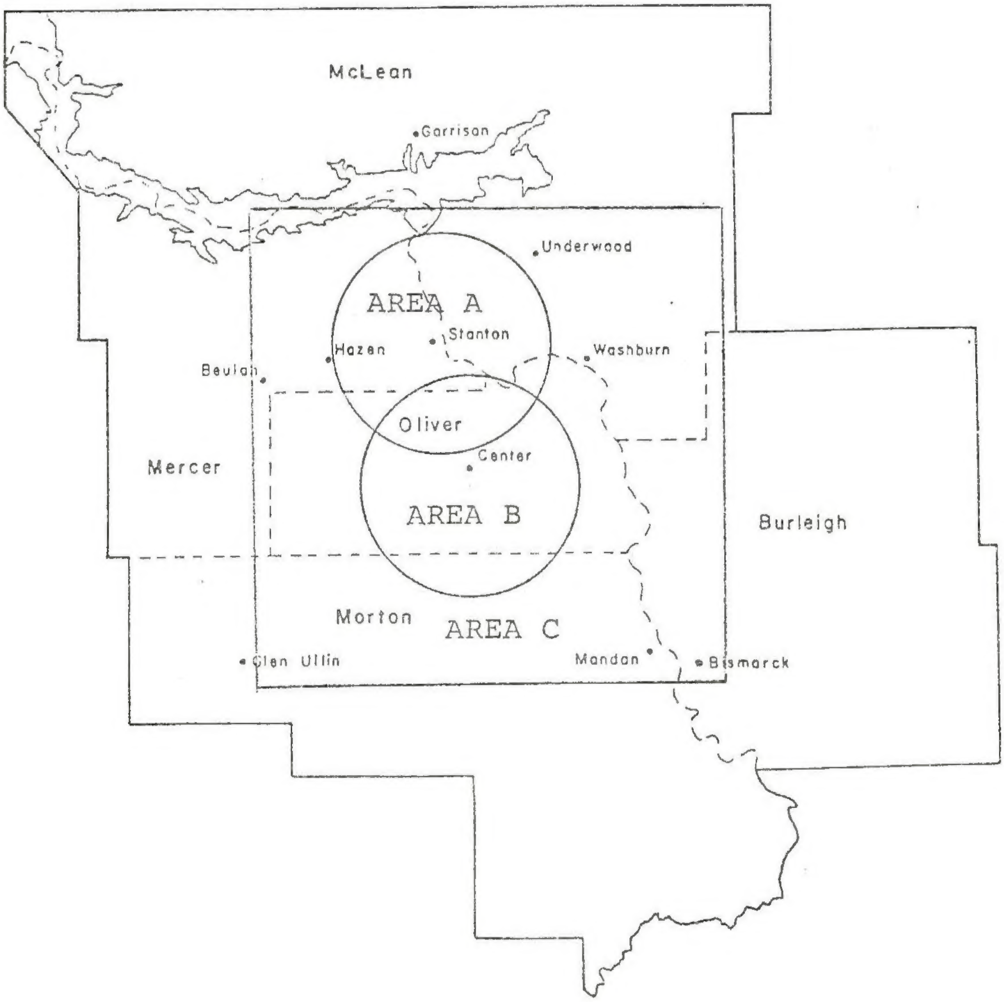


FIGURE 4

PROJECT STUDY AREA



study area. Analysis of the trace element emissions and subsequent deposition from these point sources was performed utilizing computer modeling and prediction techniques. An extensive review of the literature was also conducted to provide a basis for subsequent data analysis and interpretation.

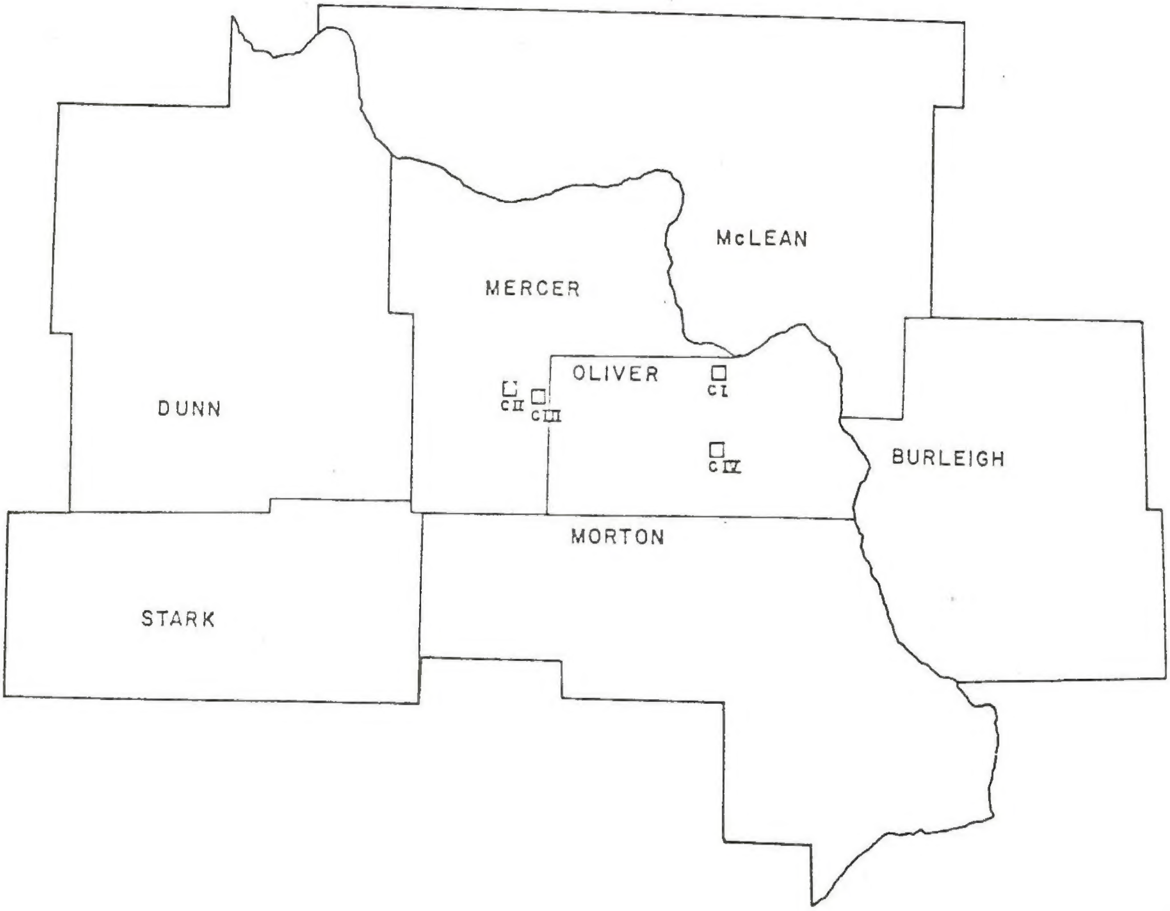
Coal

The specific lignite producing mines selected for sampling are shown on Figure 5. These mines provide the fuel source for energy conversion facilities operating in the study area. At three of the mines, samples were collected from a recently exposed vertical seam face at three depth ranges as shown in Figure 6. The samples collected from the fourth mine were core samples taken by drilling vertically through the coal bed. The seam thickness of this mine averaged approximately thirteen feet with the cores being split to represent four depth ranges (0 to 3 feet, 3 to 6 feet, 6 to 9 feet, 9 to 13 feet). The sample collection at this mine is schematically illustrated in Figure 7.

All samples from Mines C-I, C-II, and C-III, were air dried, ground, and composited by equal weight to represent the various seam locations; e.g. surface, mid-seam, and base. In addition to the composite samples, a single sample representative of each depth range was retained and analyzed along with the composites for comparison of within seam trace element variations. All samples from Mine C-IV were individually air dried, ground, and

FIGURE 5

LIGNITE COAL MINE LOCATIONS



NOTE: CI through CIV indicate lignite mine locations

FIGURE 6

COAL SAMPLE COLLECTION, MINES C-I, C-II, C-III

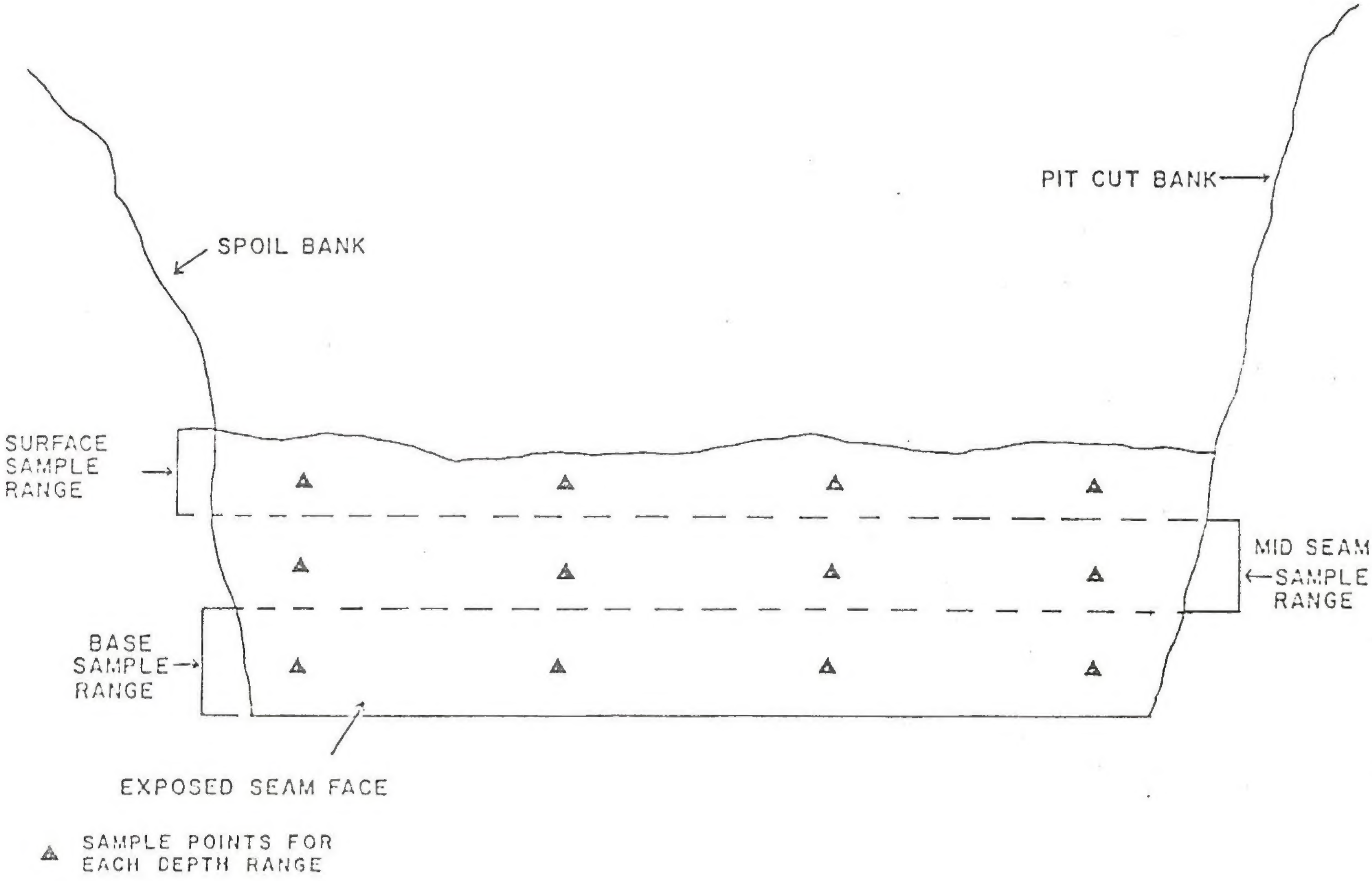
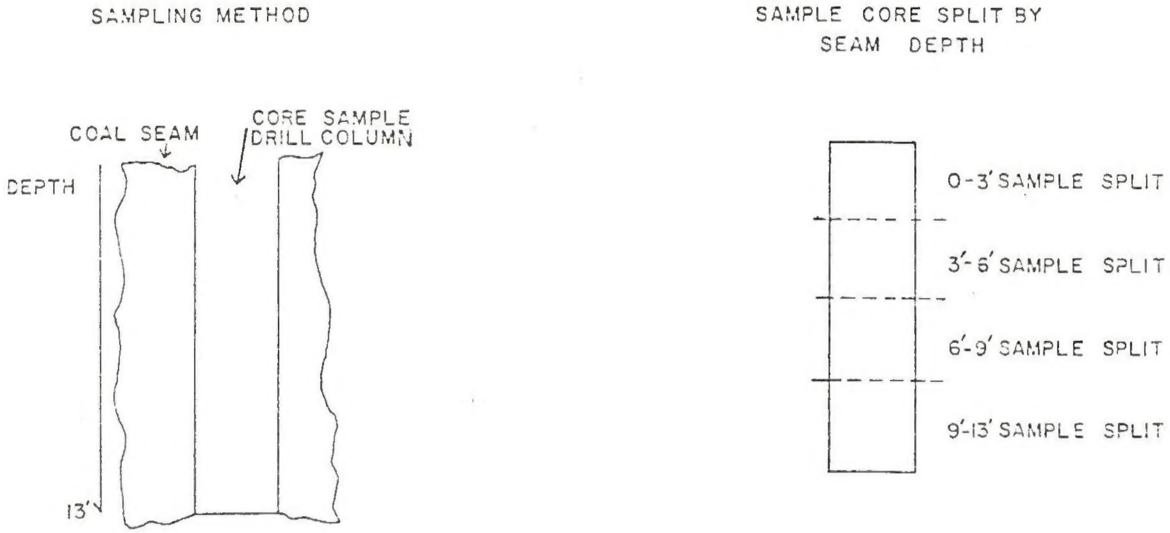


FIGURE 7

COAL SAMPLE COLLECTION, MINE C-IV



submitted for analysis. In addition, a single composite sample was prepared by taking an equal weight of each individual sample and analyzed to show a general overview of the trace element concentrations from this mine.

The actual coal sample analysis was performed by a commercial laboratory. Of the fifteen study elements, arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), molybdenum (Mo), nickel (Ni), selenium (Se), vanadium (V), uranium (U), and zinc (Zn), were analyzed by spark source mass spectroscopy. Fluoride (F) analysis was performed by ion-specific electrode, sulfur (S) by the ESCHKA method for total sulfur and mercury (Hg) by atomic fluorescence.

The ESCHKA method of total sulfur analysis utilized in this project is that found in Part 26: ASTM Designation; D3177-75. In the procedure, a weighed coal sample and the ESCHKA reagent mixture are ignited together with the sulfur precipitated from the resulting solution as barium sulfate ($BaSO_4$). The precipitate is filtered, ashed, and weighed with the analytical results reported in weight percent total sulfur.

Total fluoride in coal was determined by oxygen bomb combustion. A coal sample was digested by combustion in an oxygen medium with the fluoride subsequently trapped in a small quantity of sodium carbonate solution. The bomb was washed and the fluoride content of the washings determined by fluoride ion specific electrode measurements.

Mercury determination was performed through decomposition of the samples by combustion in an oxygen bomb. The mercury was subsequently absorbed in dilute nitric acid (3.75M) and analyzed by flameless atomic absorption. The remaining elements were analyzed by standard electrode molding techniques and spark source mass spectroscopy.

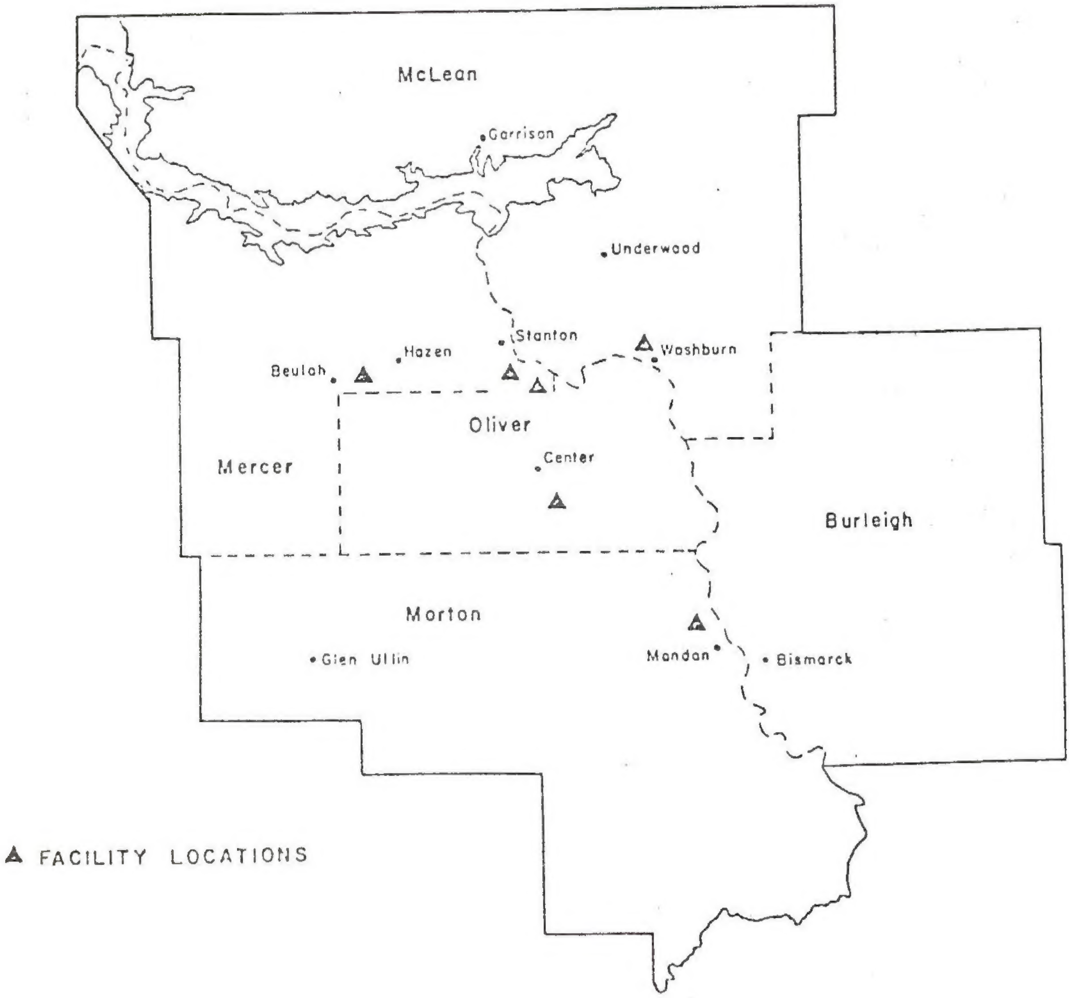
Energy Conversion Facilities

Within the environmental laboratory of the study area are six coal-fired electrical generating facilities. The locations of these facilities are shown in Figure 8. An extensive review of the physical design and operational history of each facility was performed in order to assess trace element soil enrichment from the emissions of these facilities. Of the six, three are located within the immediate study area, with the remaining facilities located on the perimeter. All six sources were operating or had operated prior to July 1, 1975.

Data collected for each facility consisted of physical design data and operational history, including annual hours of operation, periods of shutdown, sources of fuel, and annual coal usage since start up. Physical data included: stack heights, inside stack diameters, stack gas exit velocities, and stack gas

FIGURE 8

ENERGY CONVERSION FACILITIES LOCATED WITHIN STUDY AREA



exit temperatures, as well as types of emission control systems and their periods of operation since installation.

Information on the source of coal and annual fuel consumption was used in calculating trace element emission rates for each facility. The physical data and time periods of annual operations constitute climatological dispersion model inputs necessary for the mathematical projection of dispersion and resulting deposition patterns for the trace element emissions over the study area.

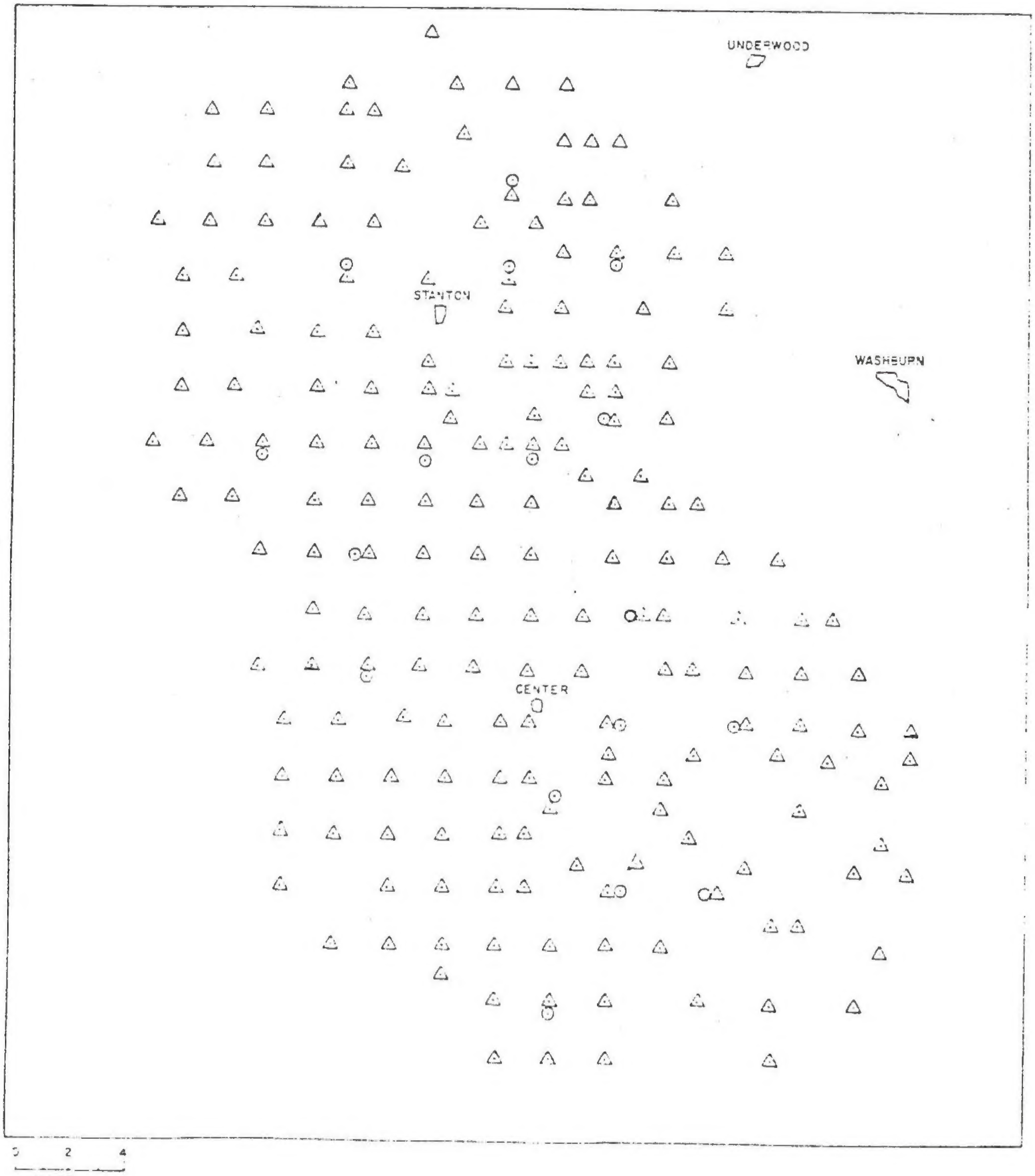
Soils

For the purpose of soil sampling, a grid system was established overlying the study area with collection points at approximately two mile intervals. Primarily, the soil samples were of native undisturbed soil. To assess the influence of agricultural activities on available soil concentrations of trace elements to crops and the possible influences of trace elements additions to the agricultural environment from energy conversion facilities, a number of soil samples from cultivated fields were collected throughout the study area.

A total of 205 locations were sampled throughout study areas A and B (See Figure 9a). Of these sites, 80% were sampled for single soil samples with 20% sampled for multiple soil samples. All single soil samples were collected at a depth of 0 to 3 inches. The multiple soil samples consisted of two 0 to 3 inch

FIGURE 9a

SOIL COLLECTION SITES



△ Undisturbed soil collection sites.
○ Cultivated field soil collection sites.

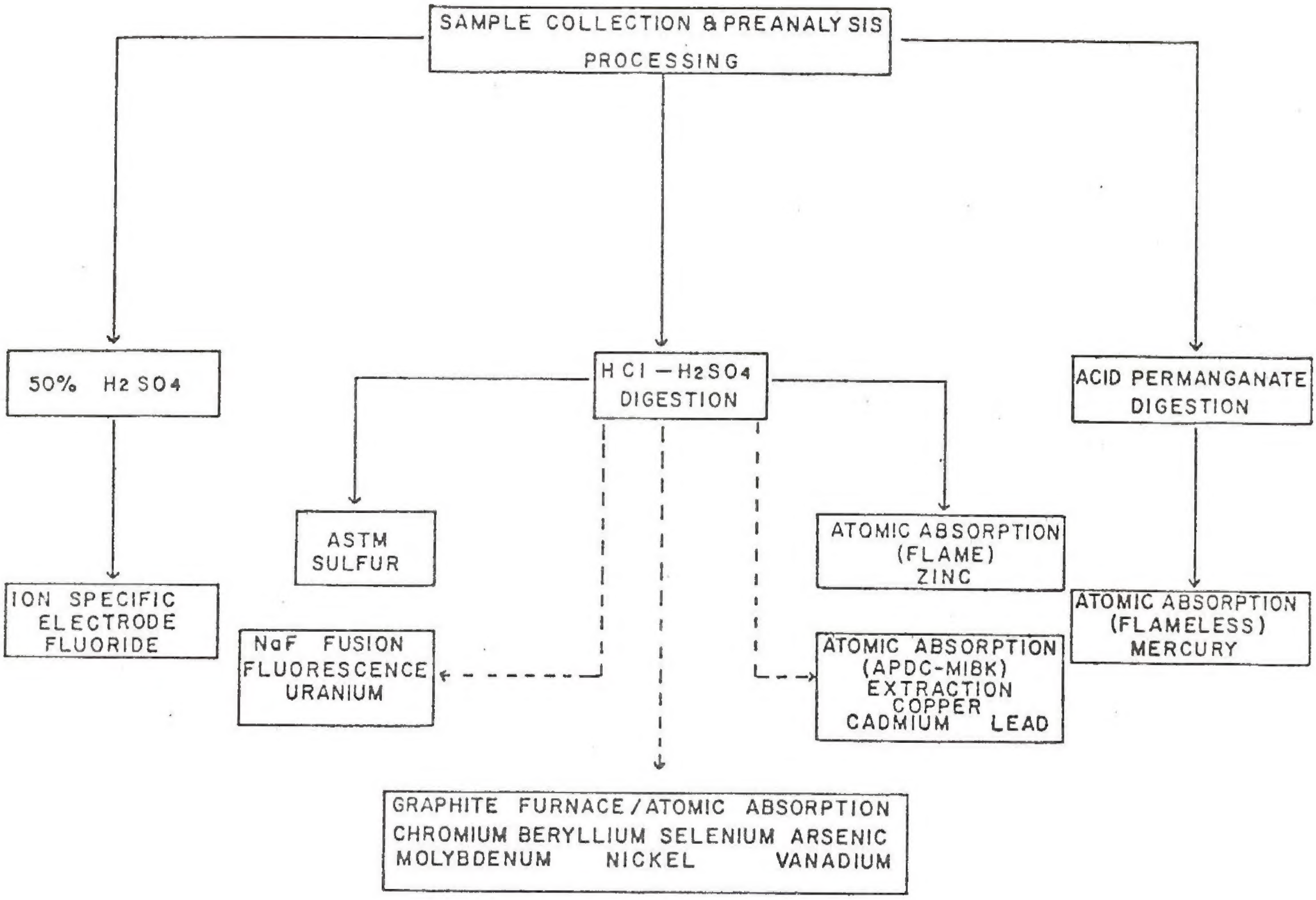
soil cores within a defined one square meter area and one soil core taken to a depth of 10 inches. The 10-inch soil core was split at the time of collection into three samples representing profile depths of 0 to 3 inches, 3 to 6 inches, and 6 to approximately 10 inches. At cultivated field soil collection sites, all samples were taken at multiple depths. The procedure involved taking a single core sample at a depth of 8 inches and splitting the core into two samples of 0 to 4 inch and 4 to 8 inch depth ranges.

At the time of sample collection, all materials were identified by site code number and brief descriptions of the sample entered in a field logbook. All samples were dried by spreading in stainless steel pans and exposed to the open air for varying lengths of time depending on the moisture content of the particular sample. After drying, the samples were weighed for total dry weight and ground to pass through a two millimeter sieve. The laboratory processing and analysis of all soil samples was performed in an identical manner.

The various analytical methodologies employed in the analysis of soil samples are presented in Figure 9b. The primary instrumentation consisted of Perkin-Elmer 403 and 503 atomic absorption spectrophotometers. Flameless atomic absorption procedures were performed with a Perkin-Elmer HGA 2100 graphite furnace in conjunction with both the 403 and 503 spectrophotometers.

FIGURE 9b

TRACE ELEMENT ANALYSIS OF SOILS


SAMPLE COLLECTION & PREANALYSIS PROCESSING
50% H_2SO_4
$HCl-H_2SO_4$ DIGESTION
ACID PERMANGANATE DIGESTION
ASTM SULFUR
ATOMIC ABSORPTION (FLAME) ZINC
ION SPECIFIC ELECTRODE FLUORIDE
ATOMIC ABSORPTION (FLAMELESS) MERCURY
NaF FUSION FLUORESCENCE URANIUM
ATOMIC ABSORPTION (APDC-MIBK) EXTRACTION COPPER CADMIUM LEAD
GRAPHITE FURNACE/ATOMIC ABSORPTION CHROMIUM BERYLLIUM SELENIUM ARSENIC MOLYBDENUM NICKEL VANADIUM

As shown in Figure 9b, soil samples were prepared for analysis by digestion with a 0.1 N acid mixture (0.05 N HCL + 0.25 N H_2SO_4), and a 1:10 ratio of soil to extractant. Zinc (Zn) was analyzed by flame atomic absorption using an acetylene flame while chromium (Cr), beryllium (Be), selenium (Se), arsenic (As), cadmium (Cd), lead (Pb), molybdenum (Mo), vanadium (V), and nickel (Ni), were analyzed using the HGA 2100 graphite furnace. Copper (Cu) was chleated and extracted with ammonium pyrrolidine dithiocarbamate-methyl isobutyl ketone (APDC-MIBK) and analyzed by atomic absorption using the acetylene flame.

Uranium (U) was analyzed by fluorescence involving a sodium fluoride fusion to a solid pellet. Sulfur (S) was analyzed by a commercial laboratory using a standard titrometric method. Mercury (Hg) analysis involved the treating of air-dried soil with a sulfuric acid-hydrogen peroxide-permanganate digestion (18N H_2SO_4-50% H_2O_2-5% $KMnO_4$). The mercury vapor generated was analyzed by the flameless atomic absorption methodology. A number of soil samples were shipped to a commercial laboratory for analysis of total fluoride. The procedure employed was steam distillation of the soil sample in a 50% sulfuric acid solution with subsequent analysis by ion specific electrode. Only twenty-five of the two hundred and five soil sample locations were analyzed for total fluoride.

Area-wide assessment of soil trace element enrichment from energy conversion facility emissions employed geochemical mapping for eleven of the fifteen elements. Maps were not prepared for mercury (Hg), molybdenum (Mo), and selenium (Se), since greater than 30% of the total soil samples collected yielded analytical values less than the detectable limit of the methodology and instrumentation employed. With respect to fluoride, no geochemical mapping of soils was performed due to the small number of samples analyzed. The geochemical maps of the study area were drawn with a computer contour plotting software package. Using the soil sample collection grid system, each sampling interval was assigned a coordinate location relating to the X and Y axes of the sampling grid. The location coordinates and corresponding analytical data for each trace element comprised the computer data inputs.

Emissions Modeling

A computer dispersion model can be used to project and assess the trace element deposition within the study area from the nearby facility emissions (Vaughan, et al., 1975). The model serves as a tool to bridge the translocation of trace elements in the form of stack effluents from coal-fired facilities to ground level receptors. The particular model used in this study to compute ground level deposition is based upon techniques and methods developed by Turner, 1970, for the United States Environmental Protection Agency (EPA).

The discussion which follows identifies the procedure by which the Climatic Dispersion Model (CDM) was modified for the purpose of projecting trace element deposition. A mathematical derivation is presented which allowed the use of an existing model capability (CDM) for the specific purpose of computing deposition.

The CDM computes the ground level concentration at a given ground level receptor from multiple point emission sources according to equation (1) below (Busse and Zimmerman, 1973).

$$(1) \qquad \overline{C}_p = \frac{16}{\pi} \sum_{n=1}^{n} \sum_{l=1}^{6} \sum_{m=1}^{6} \frac{\phi(k_n,l,m)\ G_n\ S(\ _n,z;U_l,P_m)}{\rho_n}$$

Where:

$$S(\rho_n,z;U_l,P_m) = \frac{2}{2\pi U_l \sigma_z(\rho)} \left[\exp -\tfrac{1}{2}\left(\frac{h}{\sigma_z(\rho)}\right)^2 \right] \exp\left[\frac{-0.692\rho_n}{U_l T_{\frac{1}{2}}}\right]$$

$\overline{C}_p$ = ground level concentration due to n number of point sources ($\mu g/m^3$)
$\phi(k_n,l,m)$ = joint frequency function for surface winds
ρ_n = distance from receptor to nth point source (m)
G_n = emission rate of nth point source (gm/sec)
U_l = wind speed (m/sec)
h = effective stack height for nth point source (m)
$\sigma_z(\rho)$ = vertical dispersion function (m)
P_m = Pasquill stability category
$T_{\frac{1}{2}}$ = half-life of pollutant (sec)

The decay or transformation of the pollutant is modeled in the expression by the depletion function:

$$(2) \qquad \exp\left[\frac{-0.692\rho_n}{U_l T_{\frac{1}{2}}}\right]$$

This function can be used to represent the atmospheric residence times of particles emitted from stacks of specific coal-fired facilities.

Whelpdale, 1974, demonstrated a technique for computing particle residence times in the atmosphere through the formula:

(3) $C_t = C_o \exp\ [- (v_d/H)\ t\ ]$

C_t = concentration at ground level
C_o = initial concentration at time t = 0
v_d = deposition velocity (m/sec)
H = depth of mixing (m)

Whelpdale also points out that the quantity H/v_d is the atmospheric particulate residence time. The depth of mixing (H) of the pollutant particles is defined as the depth of the mixing layer, which varies with each of the six stability classes. Substituting the relationship of $U_1 = \rho_n/t$ into Equation (2), equating the resulting function to the exponential function is Equation (3), and solving for $T_{½}$ yields:

(4) $T_{½} = 0.692\ (H/v_d)$

The terminal fall speed (v_d) for particles (less than 29 μm diameter) falling under Stokes flow at standard conditions is taken from Perkins, 1974, as:

(5) $v_d = 0.003\rho D^2$

v_d = terminal fall speed (cm/sec)
ρ = particle density (gm/cm^3)
D = particle diameter (μm)

For purposes of this study, the terminal fall speed is used interchangeably as the deposition velocity. Larger particles, or particles having higher density, will tend to fall out quicker resulting in greater surface deposition. However, the deposition velocity conceptually includes, not only fallout, but scrubbing action of surface roughness (e.g.; trees, buildings, grass).

Under conditions of known effluent mass particle size for a specific coal-fired facilities, and depth of mixing layer, the half-life ($T_{\frac{1}{2}}$) can be determined. Thus the depletion function (2) represents the rate of atmospheric fallout of effluents emitted from a stack.

The dry deposition on ground level receptors (DD) is taken from Vaughan, et al., 1975, as:

(6) $DD = C_p v_d \Delta t$

DD = deposition ($\mu g/m^2/sec$)
C_p = ground level concentration at a receptor from a single point source ($\mu g/m^3$)
v_d = deposition velocity (m/sec)
Δt = time over which deposition is to be calculated

The dry deposition conceptually represents atmospheric fallout and scrubbing action of surface receptors. Wet deposition has been modeled by other investigators to include scavenging of precipitation producing weather phenomena. Wet deposition has not been included in the modeling analysis of total deposition at this stage of this study.

The CDM computer analysis is site specific in that the stack height, stack diameter, stack exit gas velocity, stack gas temperatures, and effluent emission rate are input parameters.

The effluent emission rate (G_n) was calculated by the following formula:

(7) $$G_n = (CC/N)/K \times (1-WL) \times TEC \times AC$$

G_n = trace element emission rate (μg/sec)
CC = coal consumption by the facility over N number of years of operation up through 1975 (tons)
K = a constant; to convert units from years to seconds, and tons to grams
WL = water loading in the feed coal (%)
TEC = trace element concentration in feed coal (μg/g of coal)
AC = effluent ash trace element concentration (% of the feed coal concentration)

Since WL was not known for the coals used to feed the facilities in this study, it was assumed to be 35% in correspondence to Aresco et al., 1960. AC was assumed to be 80% of the mass of trace elements in feed coals which escaped emission control systems and exited the facility stack. This factor was applied in the calculation of deposition and may be unrealistically high for a few trace elements while low for others. (Andren et al., 1975; Fulkerson et al., 1975).

PRESENTATION OF DATA

Coal

The analytical values for all coal samples and element distributions are presented in Figures 10a through 10d. A summary of this data is presented on Table 4. A literature summary showing the ranges of element concentrations in lignite coal from North Dakota and various coal types from surrounding states is presented in Appendix A.

The results of other investigations presented on the literature composite (Table 4) cover a time span from 1935 to 1976. The wide variations in reported concentrations for many of the elements may be the result of marked advances in analytical technology in recent years. The results from this investigation show reasonable agreement with those of the Radian Corporation 1975, Basin Electric Power Cooperative 1972, and Ebasco Services, Incorporated 1973. This agreement arises from the use of comparable analytical methodologies to those employed in this study.

Energy Conversion Facilities

Energy conversion facilities constitute the primary industrial process whereby trace elements are introduced to the environment of the study area. In order to assess the possible soil enrichment of trace elements from the emissions of these facilities, it was necessary to develop an extensive review of

FIGURE 10a

FREQUENCY DISTRIBUTIONS OF TRACE ELEMENT CONCENTRATIONS
LIGNITE COAL

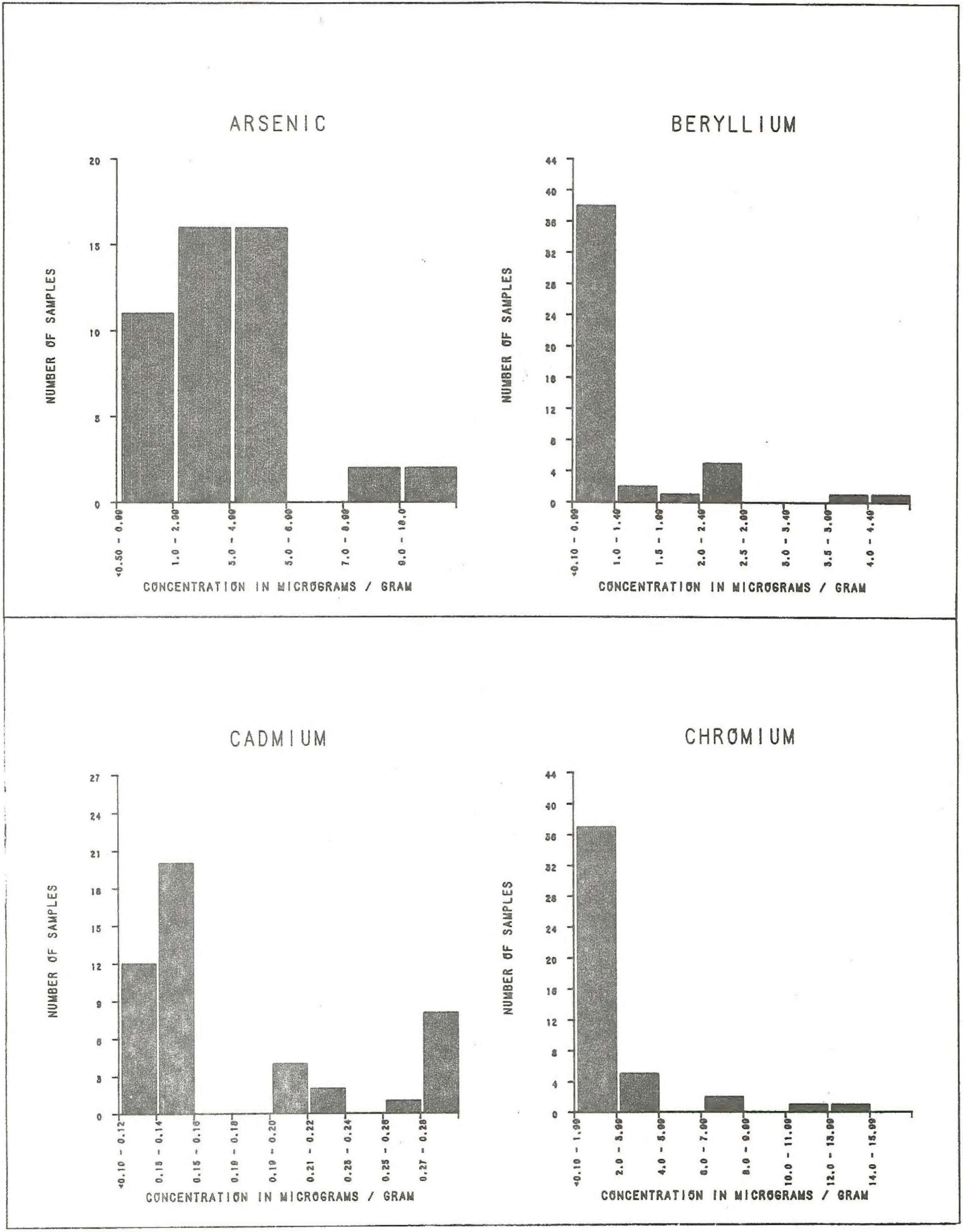


FIGURE 10b

FREQUENCY DISTRIBUTIONS OF TRACE ELEMENT CONCENTRATIONS
LIGNITE COAL

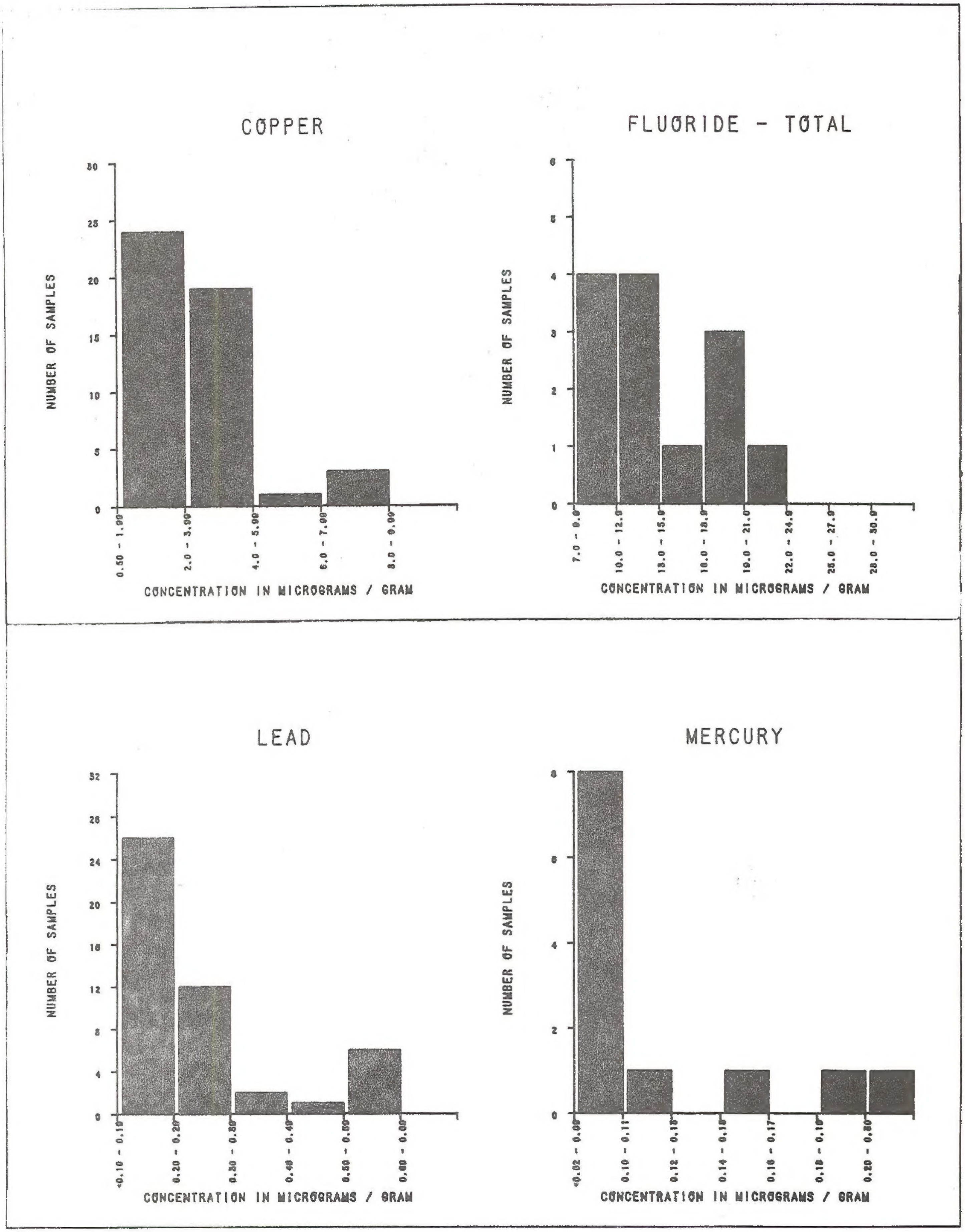


FIGURE 10c

FREQUENCY DISTRIBUTIONS OF TRACE ELEMENT CONCENTRATIONS
LIGNITE COAL

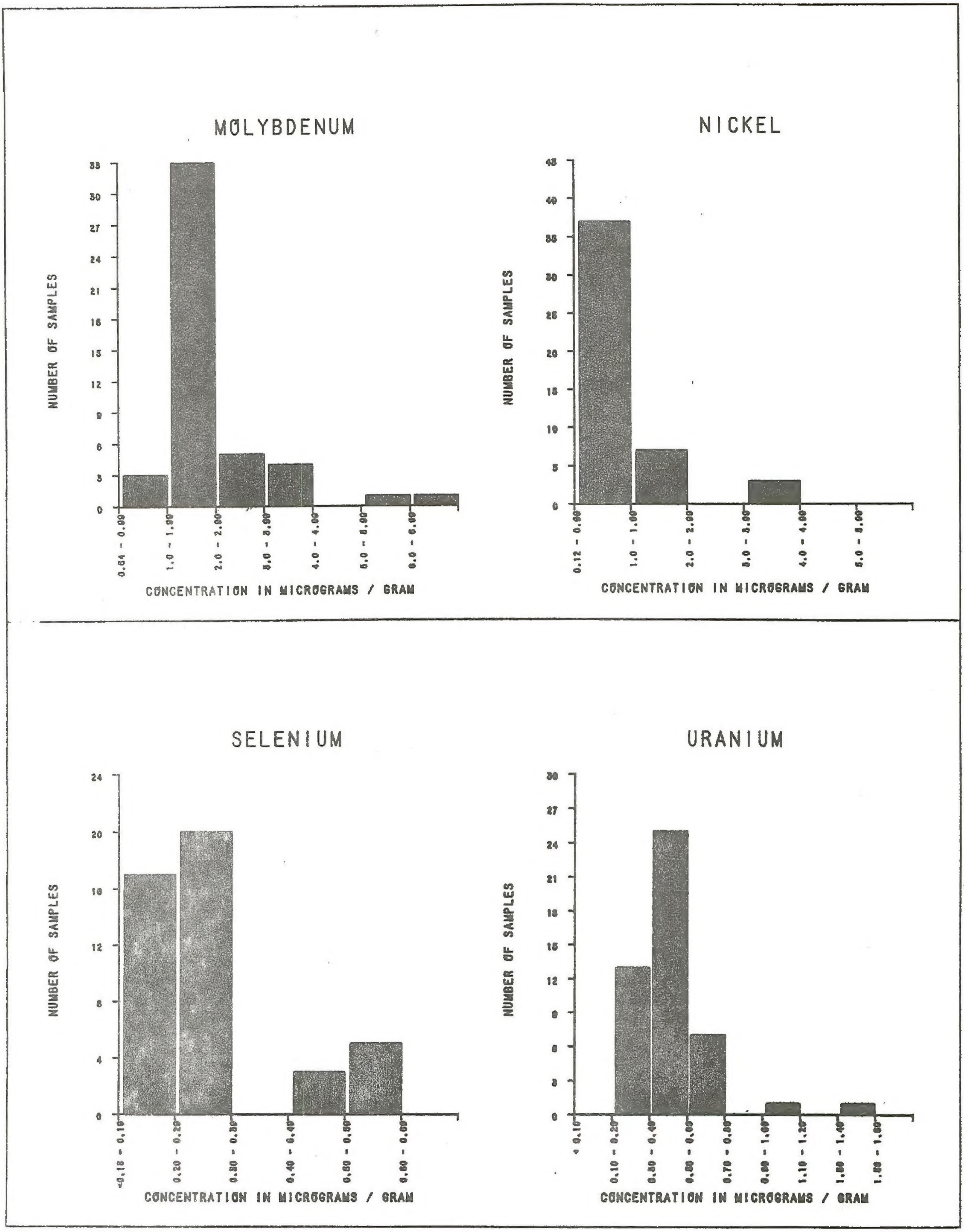
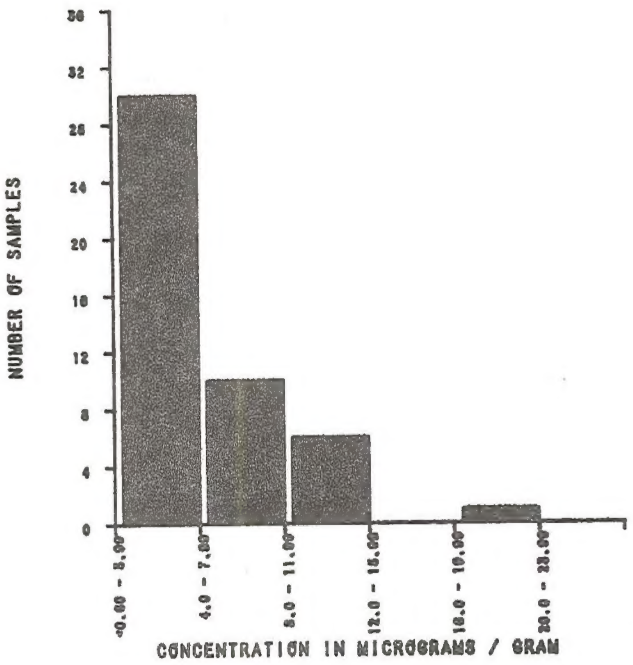
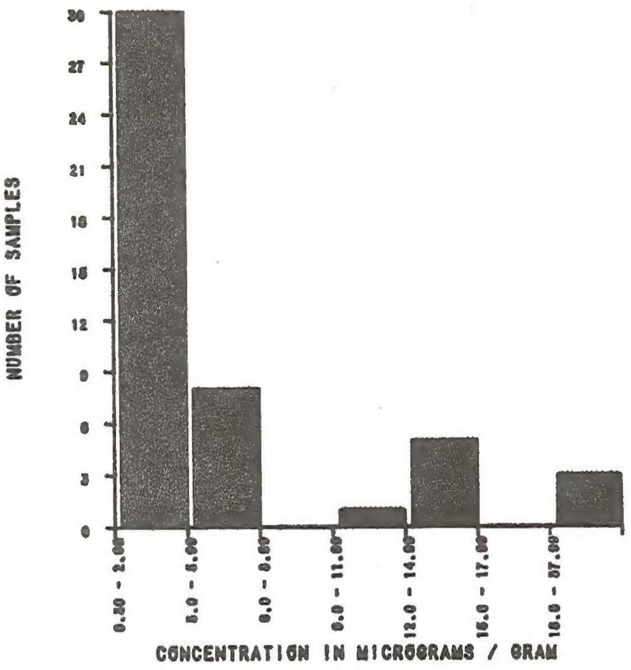


FIGURE 10d

PREQUENCY DISTRIBUTIONS OF TRACE ELEMENT CONCENTRATIONS
LIGNITE COAL


VANADIUM


ZINC

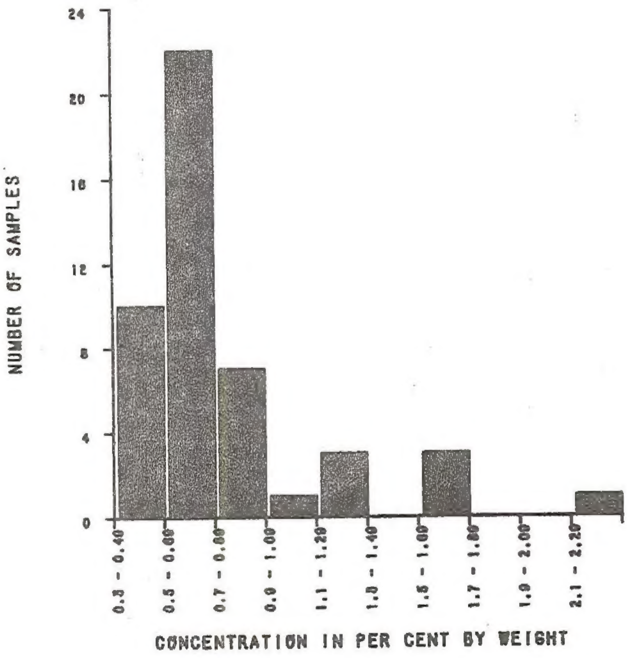

SULFUR

TABLE 4

COAL DATA SUMMARY

Element	Study Data (µg/gm)			Literature Summary[4] (µg/gm)
	Min.	Max.	Arithmetic Mean	Expected Average Conc. Range
Arsenic	< 0.54	18.0	2.07	5.0
Beryllium	< 0.10	4.3	0.75	0.1 - 4.0
Cadmium	< 0.10	0.27	0.13	0.10 - 0.53
Chromium	< 0.10	13.0	1.29	4.0
Copper	0.53	7.7	2.88	< 1.0 - 40.
Fluoride[1]	7.4	25.0	15.53	25. - 150.
Lead	< 0.10	0.51	0.26	0.5 - 7.0
Mercury	< 0.02	0.28	3/	< 0.2
Molybdenum	0.64	6.4	1.63	< 1.0 - 17.0
Nickel	0.12	5.8	0.93	1.3 - 40
Selenium	< 0.18	0.58	0.30	0.4 - 8.0
Uranium	< 0.10	1.4	0.47	
Vanadium	< 0.60	19.0	2.69	0.2 - 25.0
Zinc	0.30	37.0	2.56	2.9
Sulfur[2]	0.37%	2.29%	0.72%	< 0.7% - 1.5%

1/ As total fluoride.

2/ As total sulfur, % weight.

3/ > 30% of samples less than detectable limit, resulting in arithmetic mean which would fall below <0.02.

4/ Composite from literature search with averages from existing lignite coal data.

the physical design and operational history of each unit influencing the research area. A summary of this data for the six electrical generating stations influencing the study area is presented in Table 5.

The following information is a brief summary of each electrical generating facility considered in this investigation, along with schematics representing typical power plant designs. The schematics presented are not necessarily exact representations of the specific facilities in operation within the study area but are "typical" of that specific power plant design.

Facility P-I, began operation in the study area in late 1970. This is a 250 megawatt electrical generating unit located within the immediate study area and fired with lignite coal. The boiler arrangement is of the cyclone-fired type. A multi-cyclone system was used for fly ash control until mid 1975. A schematic of this type facility, including all inlet and outlet streams, is shown in Figures 11a and 11b with the exception of the 300 foot stack, Figures 11a and 11b are also applicable to Facility P-II. In mid 1975, the cyclone collection system of Facility P-I was removed and an electrostatic precipitator installed for control of particulate emissions. However, for the purpose of the trace element environmental deposition analysis, the emission control for this facility was multi-cyclone.

TABLE 5

SUMMARY OF ENERGY CONVERSION FACILITY
HISTORY AND STRUCTURAL DATA AS OF JULY 1, 1975

Facility	MW Capacity	Years of Operation	Total Raw Coal[1] usage 7-1-75 tons	Average[1] annual hours operation	Emission[2] control devices	Mass particle size (dia in μm)	Number of stacks	Height (ft)	Inside diameter (ft)	Gas exit temp (°F)	Gas exit velocity (ft/sec)
P-I	250	5	7,538,492	7,919	Multi-cyclone	10	1	300	19	330	70
P-II	85	21 12	3,525,000 3,900,000	8,000 8,000	Multi-cyclone	10	1 1	125 125	7 12	345 310	50 50
P-III	15	48 37 25	1,890,000 590,000 725,000	5,396 5,162 8,000	None None Mech. Dust Collector	20[4] 20[4] 10	2 1 2	74 87 74	5'6" 7'5" 5'6"	500 500 500	40 40 40
P-IV	180	9	7,018,037	7,426	Multi-cyclone	5	1	255	15	338	90
P-V	220	10	12,604,900	7,727	Multi-cyclone	5	1	350	15	350	74
P-VI[3]	10	40	2,490,180	7,000	None	20[4]	1	80	6	350	50[1]

1/ Calculated and/or estimated from company information (annual coal usage times years of operation)

2/ Status as of July 1, 1975

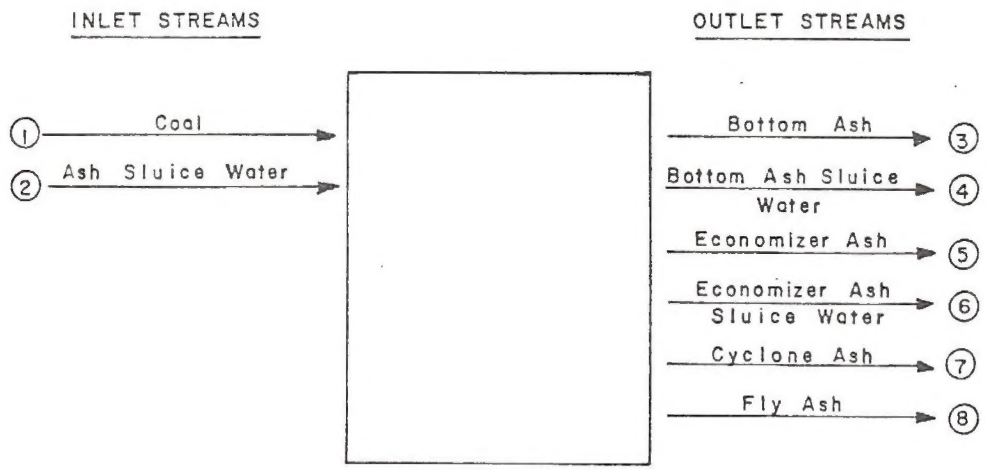
3/ Facility closed in 1969

4/ Available data indicate that 95% of stack particles have sizes less than 20 μg.

SOURCE: Division of Environmental Engineering, North Dakota State Department of Health 1977

FIGURE 11a

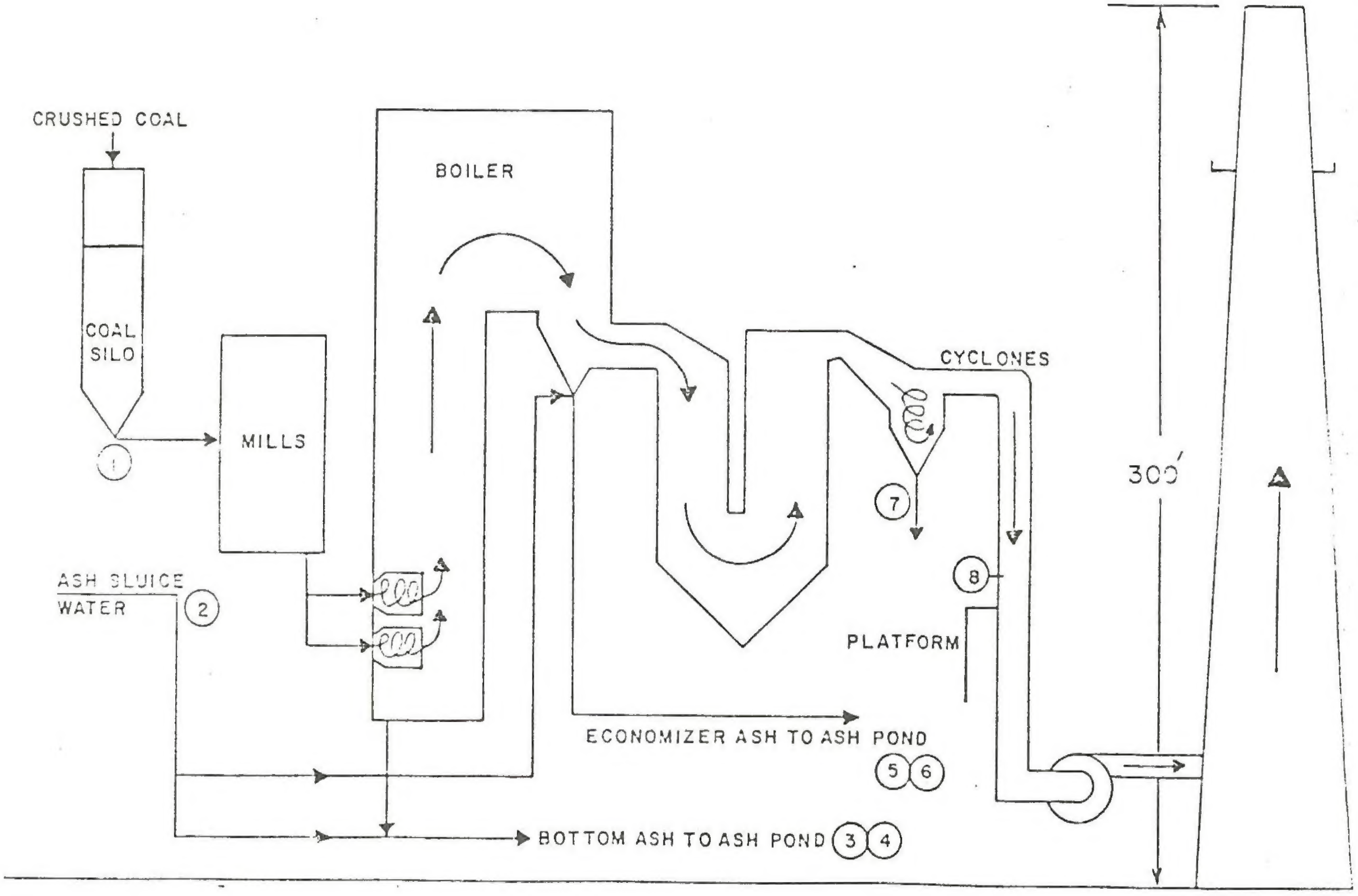
INLET AND OUTLET STREAMS OF ELECTRICAL GENERATING FACILITIES SIMILAR IN DESIGN TO FACILITY P-I AND FACILITY P-II



SOURCE: Radian Corporation 1975

FIGURE 11b

DESIGN SCHEMATIC OF AN ELECTRICAL GENERATING FACILITY SIMILAR IN DESIGN TO FACILITY P-I AND FACILITY P-II



SOURCE: Radian Corporation 1975, with modifications by the North Dakota State Department of Health.

Facility P-II began operations in 1954. This facility operated as a single unit with one 125 foot stack until 1963, when a second unit and an additional 125 foot stack were added. Both units operated with multi-cyclone collection systems for particulate emission control until late 1975. During 1975, the stacks on both units were replaced by 300 foot stacks, and one electrostatic precipitator installed on each boiler. However, for the purpose of the potential environmental deposition analysis, this facility was considered as multi-cyclone systems with 125 foot stacks.

Facility P-III has been in operation for a period of 48 years. P-III is the oldest of the five operating facilities in this study. Operations at this facility began in 1927 with the basic design as a two-unit facility with two 74 foot stacks and no emission control devices. In 1938, the facility was expanded with the addition of a third unit and an 87 foot stack. The facility maintained operation with three units until 1949 when two additional generating units and two additional 74 foot stacks were added. The additional units were equipped with mechanical dust collectors at installation. This comprises the operational status of Facility P-III as considered in this study.

In 1976, the stacks serving Units 3, 4, and 5, were replaced by a single 100 foot stack with an electrostatic precipitator replacing the mechanical dust collection system. A schematic of the inlet and outlet streams for a typical electrical generating facility of the original design such as Facility P-III is presented in Figures 12a and 12b. These schematics are also applicable to the original design of Facility P-VI.

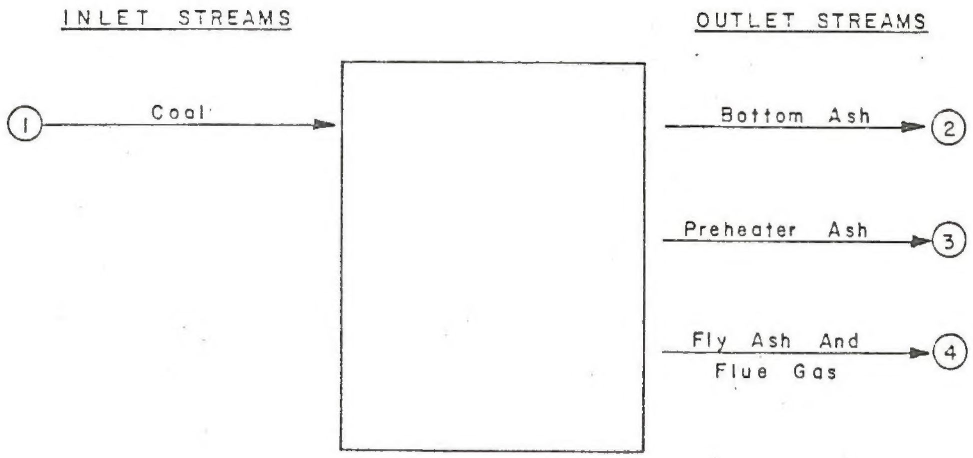
Facility P-IV has been in operation since 1966. This facility is located within the immediate study area and has operated as per the data presented on Table 5 through the initiation of this study in 1975. In 1976, the mechanical precipitator was replaced by an electrostatic precipitator for control of particulate emissions. Figures 13a and 13b present schematics of the inlet and outlet stream flows of an electrical generating unit similar to Facility P-IV. These schematics are also representative of the basic design of Facility P-V.

Facility P-V began its operation in early 1966. The initial emission control equipment consisted of a multi-cyclone system for particulate collection. In 1974 the system was replaced by an electrostatic precipitator. This facility was considered to operate from 1966 to 1975 as per the data presented in Table 5.

Facility P-VI was a small generating station which ceased operations in 1969. This facility was evaluated for its influence on the study area over an operational period from 1926 to 1969. This facility operated with two boiler units from 1926 to 1929 when a third unit was added. In 1945 a fourth boiler

FIGURE 12a

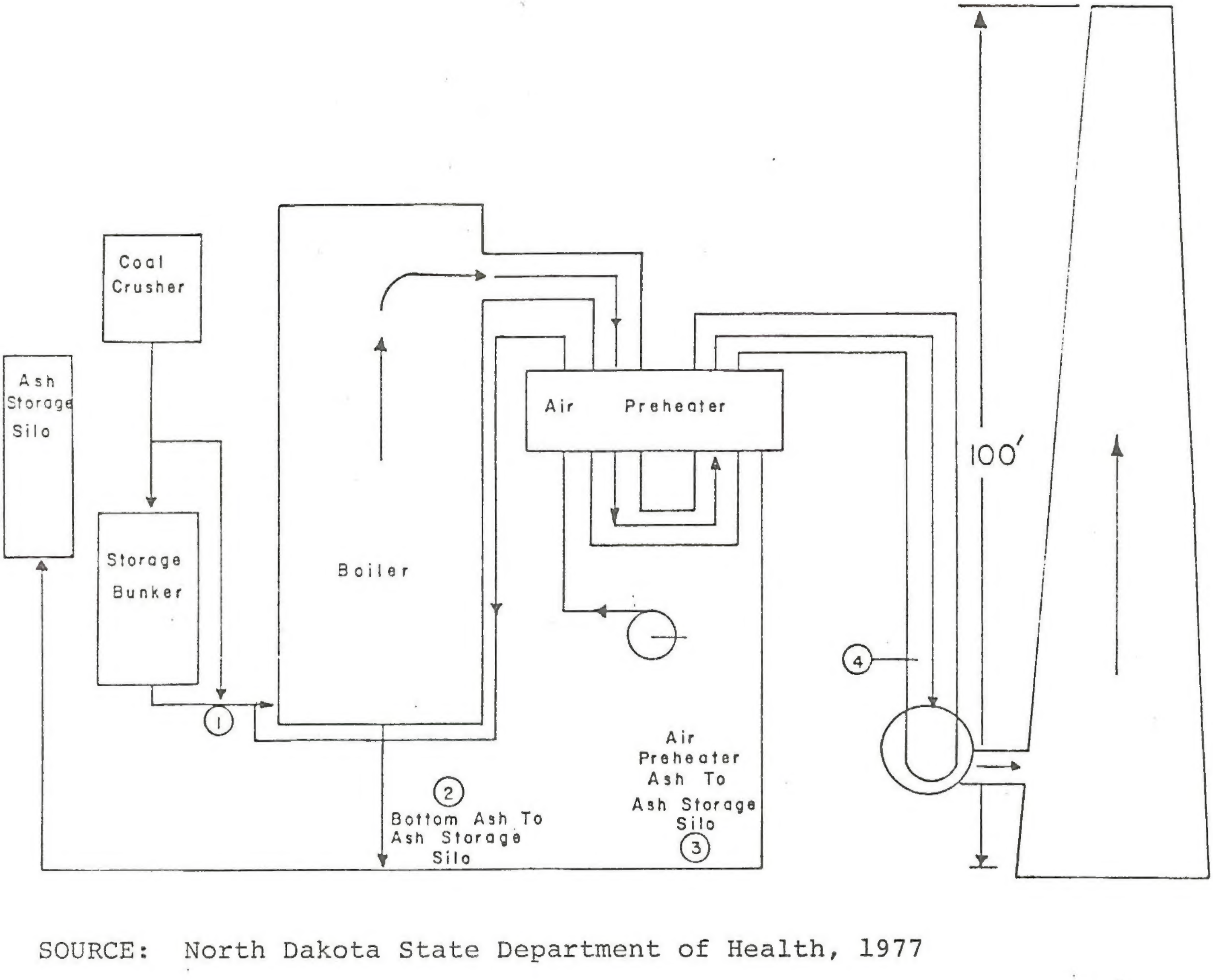
INLET AND OUTLET STREAMS OF ELECTRICAL GENERATING FACILITIES SIMILAR IN DESIGN TO FACILITY P-III AND FACILITY P-VI



SOURCE: North Dakota State Department of Health, 1977

FIGURE 12b

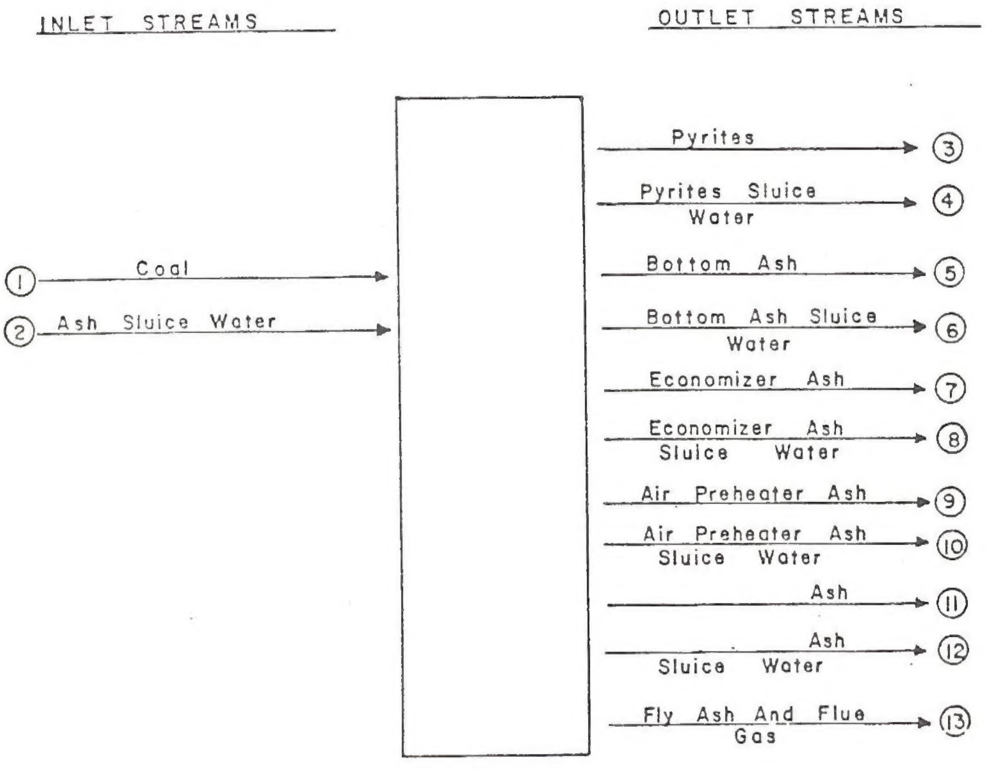
DESIGN SCHEMATIC OF AN ELECTRICAL GENERATING FACILITY SIMILAR IN DESIGN TO FACILITY P-III AND FACILITY P-VI



SOURCE: North Dakota State Department of Health, 1977

FIGURE 13a

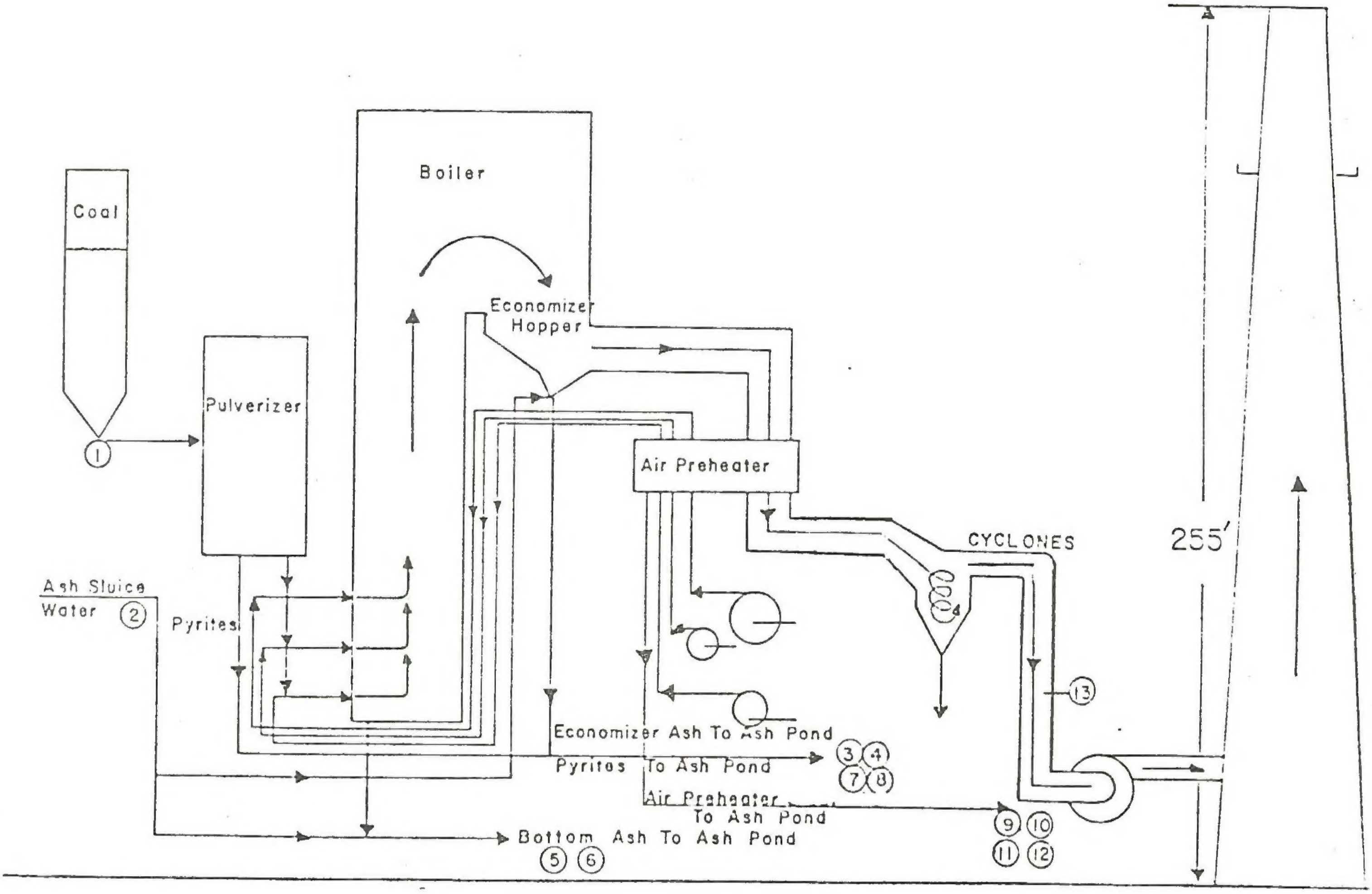
INLET AND OUTLET STREAMS OF ELECTRICAL GENERATING FACILITIES SIMILAR IN DESIGN TO FACILITY P-IV AND FACILITY V



SOURCE: Radian Corporation 1975, with modifications by the North Dakota State Department of Health.

FIGURE 13b

DESIGN SCHEMATIC OF AN ELECTRICAL GENERATING FACILITY SIMILAR IN DESIGN TO FACILITY P-IV AND FACILITY P-V



SOURCE: Radian Corporation 1975, with modifications by the North Dakota State Department of Health.

unit was added and the operation continued at this level until 1964 when the facility was temporarily closed.

Operations at Facility P-VI were resumed for a short period of time in 1967 with final closure coming in late 1969. Throughout the lifetime of this facility, it had an 80 foot stack and had been operated with no emission control devices. Records concerning coal usage and annual hours of operation are incomplete. These data presented in Table 5 for this facility consequently is an estimate with respect to these parameters as well as the stack gas exit velocity.1/

During the time interval of this investigation, there were several 440 megawatt lignite-fired electrical generating facilities under construction. Since these facilities were not operational prior to this investigation, they were not considered in the environmental assessment of the potential trace element deposition.

Soil

The soil analytical results and sample range distributions are presented in Figures 14a through 14d. A summary of this data showing minimum, maximum and arithmetic mean concentrations in micrograms per gram as well as a literature composite of expected concentration ranges in "normal" soils is presented in Table 6. Appendix B is a presentation of a literature search providing the base data for establishment of ranges of concentrations for each trace element presented in Table 6.

1/ Personal Communication.

FIGURE 14a

FREQUENCY DISTRIBUTION OF TRACE ELEMENT CONCENTRATIONS
SURFACE SOILS

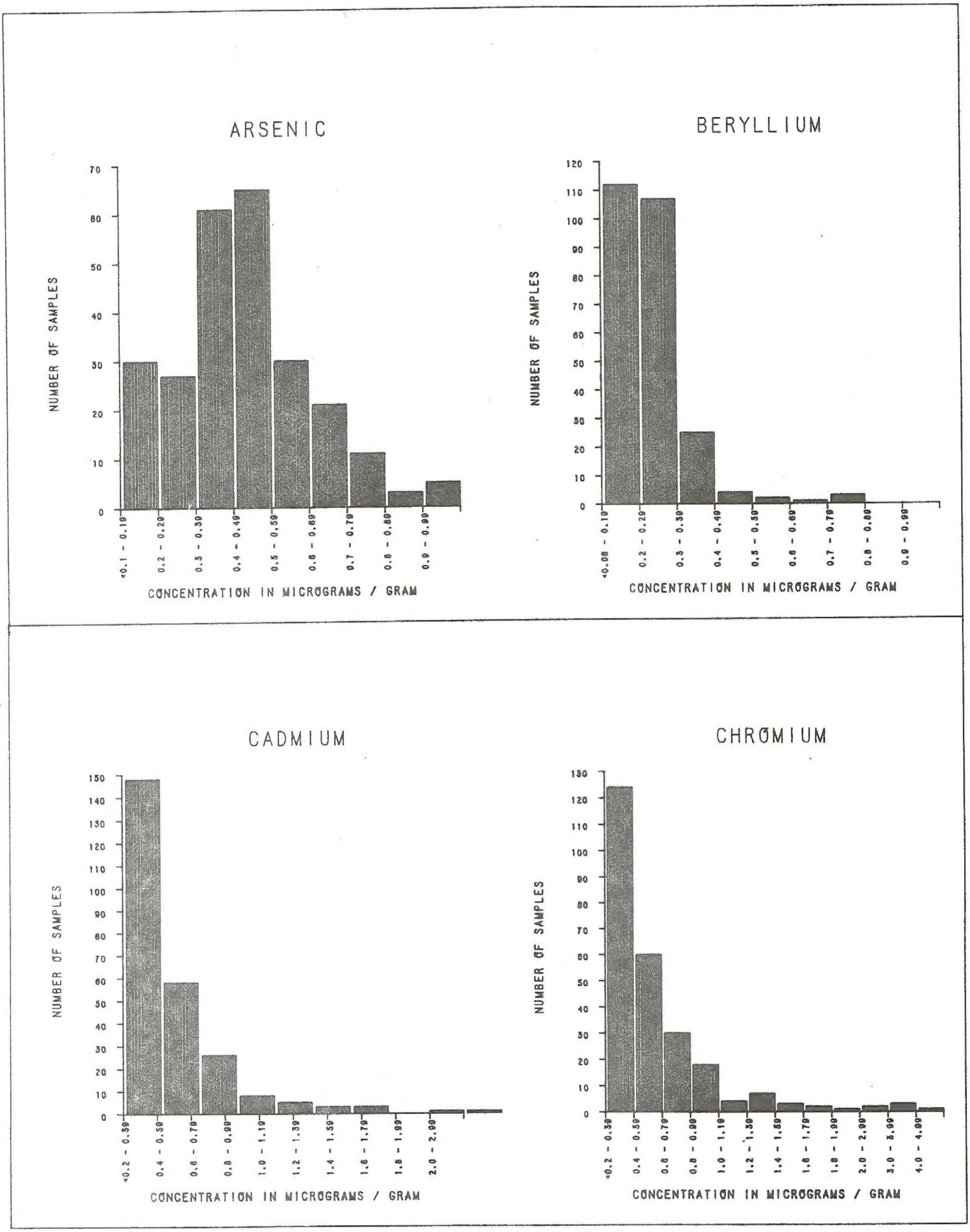


FIGURE 14b

FREQUENCY DISTRIBUTION OF TRACE ELEMENT CONCENTRATIONS
SURFACE SOILS

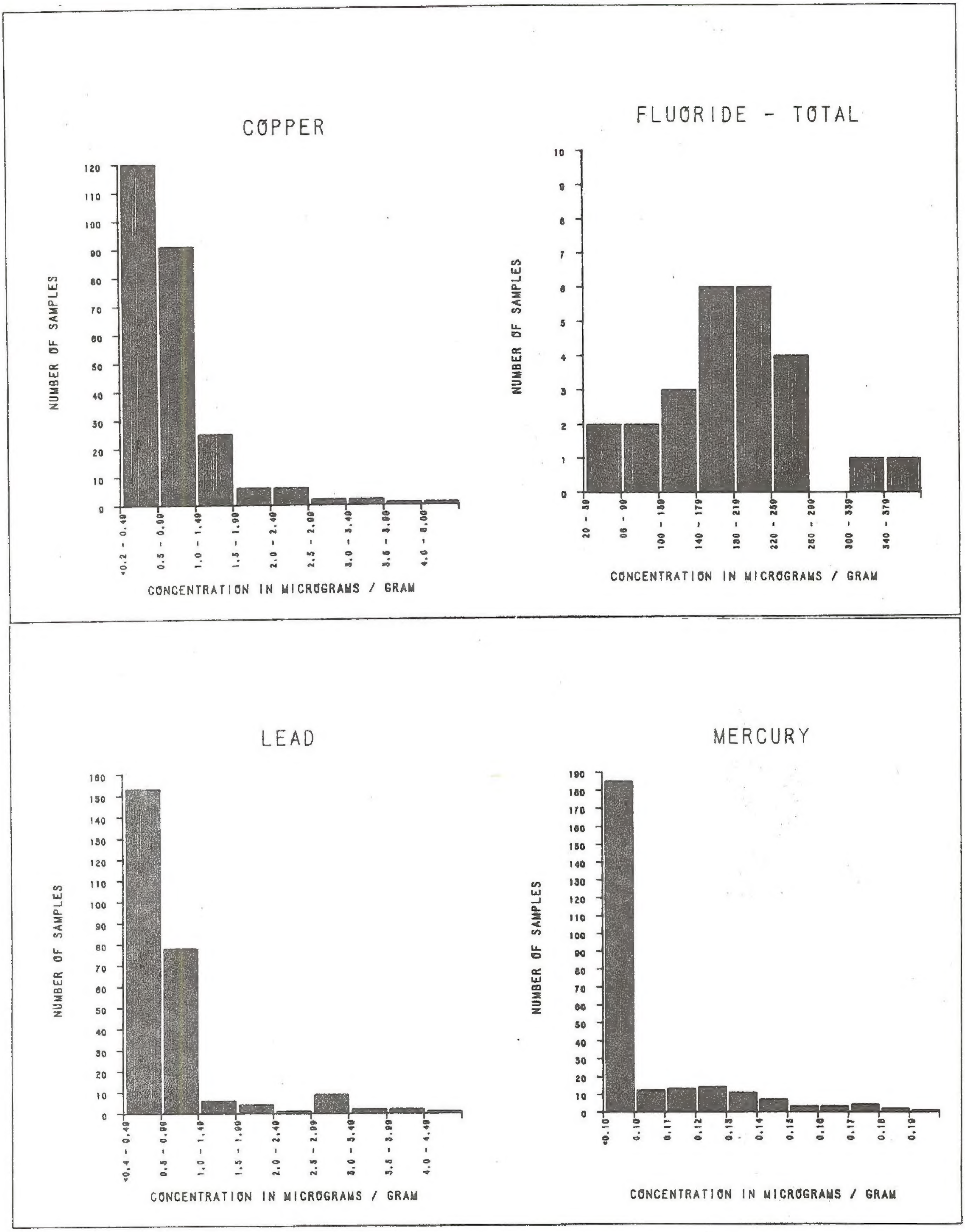


FIGURE 14c

FREQUENCY DISTRIBUTION OF TRACE ELEMENT CONCENTRATIONS
SURFACE SOILS

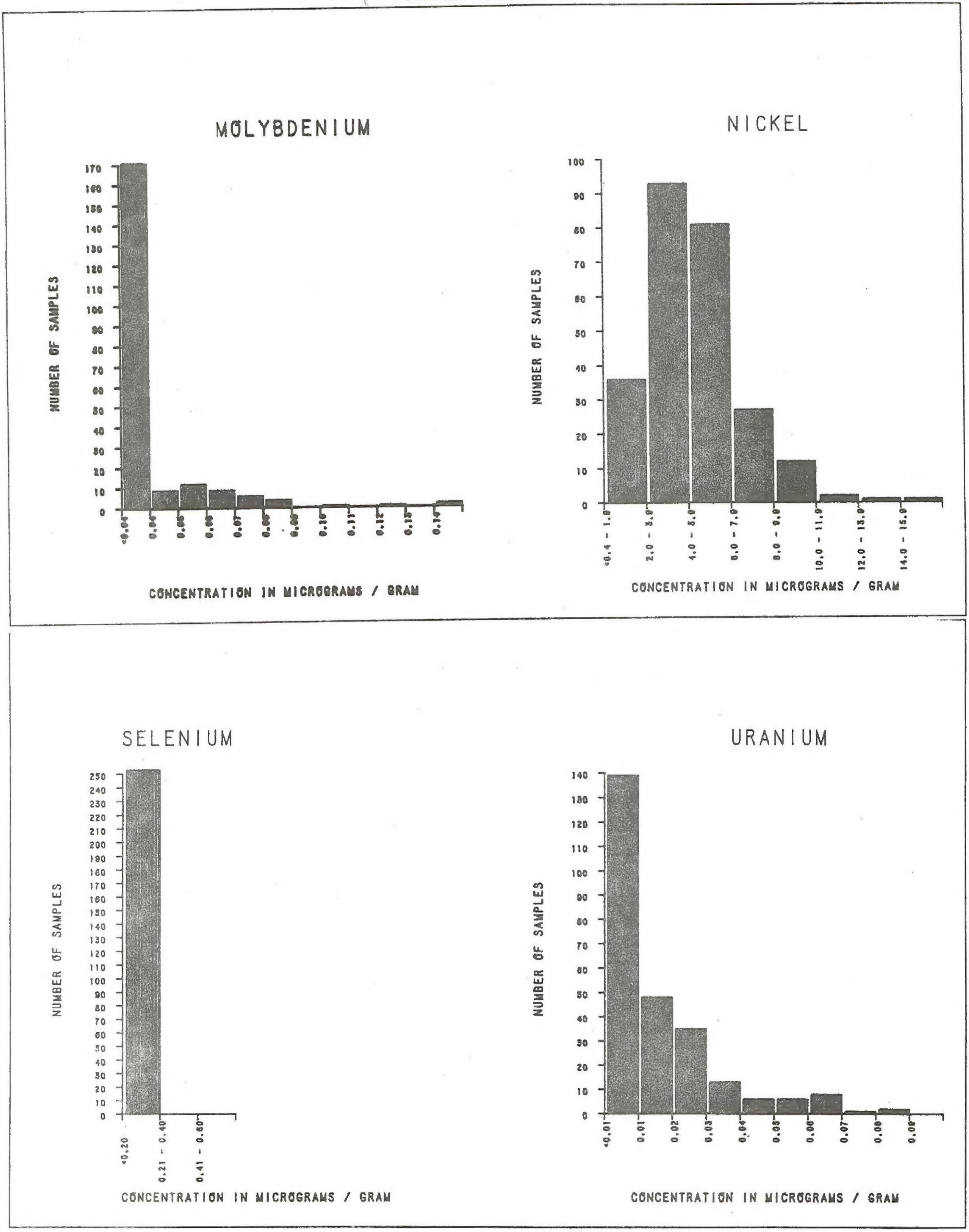


FIGURE 14d

FREQUENCY DISTRIBUTION OF TRACE ELEMENT CONCENTRATIONS
SURFACE SOILS

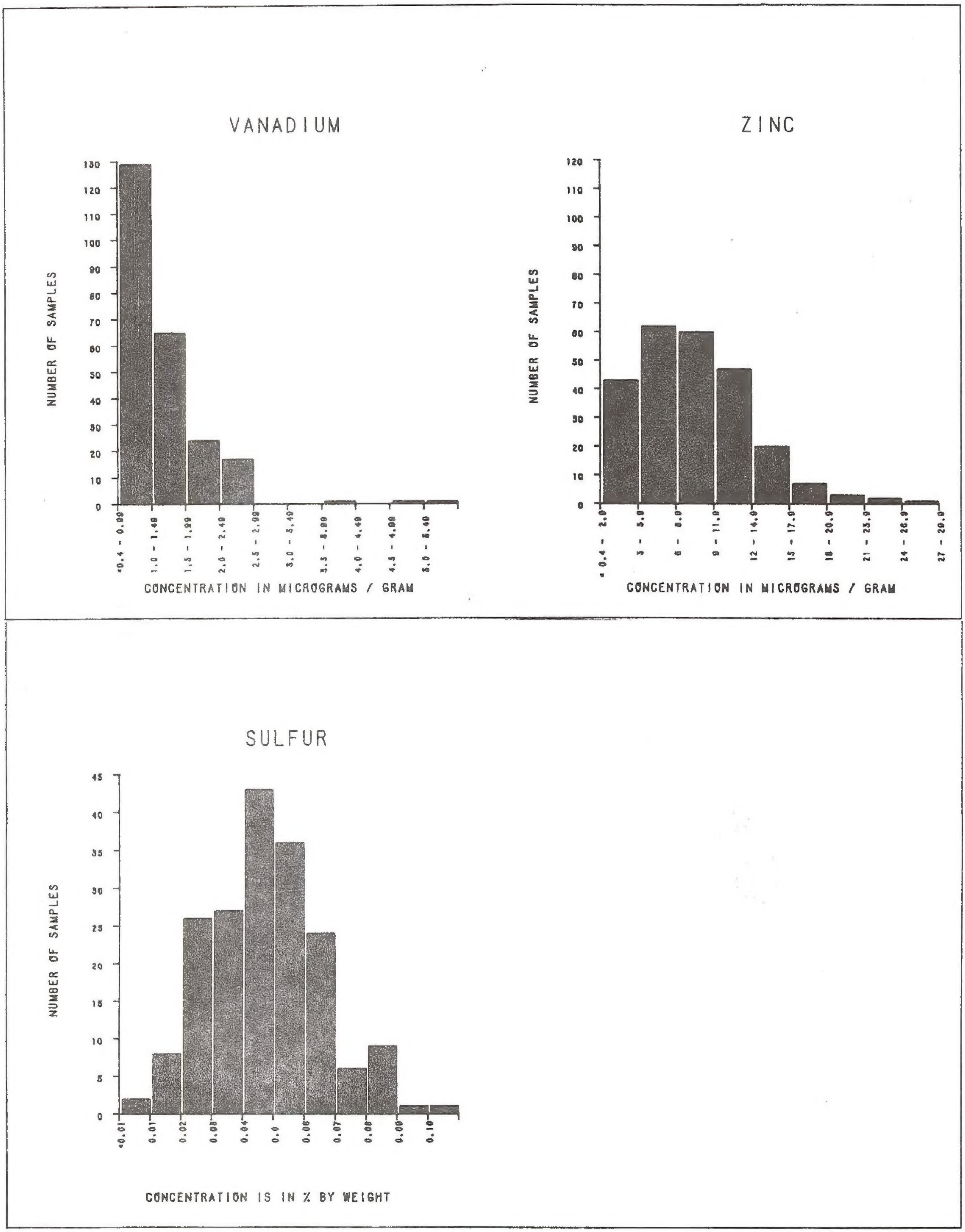


TABLE 6

SOIL DATA SUMMARY
SURFACE SAMPLES FROM 1975

	Study Data (µg/gm)			Literature Summary (µg/gm)
	Min.	Max.	Arithmetic Mean	Expected Average Conc.3/
Arsenic	< 0.10	0.95	0.42	2.5 - 108.
Beryllium	< 0.08	0.76	0.21	0.1 - 40.
Cadmium	< 0.20	4.0	0.44	0.01 - 7.0
Chromium	< 0.20	4.90	0.52	1.0 - 100.
Copper	< 0.20	5.60	0.70	2.5 - 200.
Fluoride1/	23.0	360.0	172.44	100 - 300
Lead	< 0.40	4.48	4/	<0.5 - 15.0
Mercury	< 0.10	0.19	4/	<0.05 - 0.14
Molybdenum	< 0.04	0.14	4/	<0.10 - 5.0
Nickel	< 0.40	15.2	4.27	<1.0 - 100.
Selenium		<0.20	4/	0.10 - 6.0
Uranium	< 0.01	0.08	4/	
Vanadium	< 0.40	5.0	1.03	3.0 - 250.
Zinc	< 0.40	60.0	7.22	10.0 - 300.
Sulfur2/	< 0.01%	0.10%	0.04%	0.01% - 0.06%

1/ Data presented as total fluoride.

2/ Data presented as total sulfur, % weight.

3/ Composite average from literature review.

4/ Greater than 30% of samples less than detectable limit giving a mean of less than (<) 0.01 limit for Uranium, <0.20 for Selenium, <0.04 for Molybdenum, <0.10 for Mercury, and <0.4 for Lead.

DISCUSSION

Coal

The Federal Energy Administration, 1975, has extensively described the Fort Union Coal Formation in the northern Great Plains. According to the FEA, the Fort Union region is the largest of the northern Great Plains coal producing areas. It encompasses the western half of North Dakota and parts of South Dakota and Montana. It has been estimated that the total lignite coal reserves in this region are approximately 440 billion tons, which makes it the largest coal reserve in the entire United States.

Most of the coal in North Dakota is found in the Lebo, Tongue River, and Sentinel Butte members of the Fort Union formation of Paleocene Age. A few thin lignite beds have also been found to occur near the base of the underlying Wasatch formation of Paleocene and Eocene Age, in the Basal Tullock member of the Fort Union formation, and the underlying Hellcreek formation of late Cretaceous Age.

The coal beds of western North Dakota are discontinuous and vary greatly in thickness. More than one hundred beds have been identified by the North Dakota Geological Survey, (1973), but only a small percentage of these are of commercial thickness. The Fort Union formation ranges in thickness from 425 to 775 feet in South Dakota up to 1,500 feet in some areas of eastern

Montana. The coal throughout most of the Fort Union region is lignite in rank. However, westward along the formation from the Montana-North Dakota boundary (see Figure 1), the rank of the coal increases to Sub-bituminous C near Miles City and Sub-bituminous B further west. The Fort Union region merges with the Powder River Basin along a vague northwest-trending boundary in east central Montana. This boundary is defined roughly by the change in rank of coal from lignite to sub-bituminous.

The trace element concentrations obtained through this study from specific mine sources of the Fort Union formation in western North Dakota have been shown to agree with the work of other investigators (as presented in Appendix A). The variation in analytical data that exists between the reported values in this investigation and those of the literature can be attributed to several factors. These factors include; the number of samples analyzed, treatment of the samples prior to analysis, the specific analytical instrumentation and methodology, the methods of statistical reduction of data, and most importantly the natural geochemical variation within and between the different coal beds investigated.

The geochemical variation found between coal beds and within the various seams of a specific bed is difficult to assess and largely depends upon the hydrology in the area of a given coal-producing seam. According to Nicholls, 1968, trace element accumulation in various coal seams and locations within coal beds is based on groundwater circulation through seam margins, against surrounding strata, or against shale or dirt partings running through the various seams. Higher concentrations of trace elements usually occur in the outer edges of seams due to initial contact with circulating groundwater.

The geochemical variations of elements within a coal seam was not extensively studied in this investigation. However, this natural variation can be seen on Tables 7, 8, and 9, for Mines C-I, C-II, and C-III, respectively. These tables show the results of a composite sample and corresponding single sample for each of the depth ranges at Mines C-I, C-II, and C-III. This geochemical variation becomes significant when trace element emission calculations for energy conversion facilities are based on trace element concentrations in feed coal. The data in these tables demonstrate that the calculation of emissions could show an extremely wide range in expected rates.

A presentation of trace element variations observed at the sampling depth ranges for each mine are shown in Figures 15, 16, 17, and 18. It appears that larger trace element concentrations in Mine C-I occur in the upper two-thirds of the seam. For Mine C-II, it appears that the higher concentrations of elements occur in the surface of the seam. Element concentrations are slightly higher in the mid-seam area of Mine C-III. The seam depth variations for Mine C-IV show a general trend toward higher concentrations at the lower seam depths. On the basis of

TABLE 7

COMPARISON OF SINGLE SAMPLE TO COMPOSITE SAMPLE FROM THREE LOCATIONS WITHIN COAL SEAM. MINE C-I (1975)

Element1/	Surface		Mid-Seam		Base	
	Comp.	Single	Comp.	Single	Comp.	Single
As	1.8	7.6	3.5	3.5	1.3	3.5
Be	1.5	1.0	1.0	1.0	0.2	< 0.10
Cd	0.13	0.13	0.13	0.13	0.13	< 0.10
Cr	2.9	0.67	2.9	1.3	0.51	0.67
Cu	1.8	0.77	7.7	0.77	0.77	0.77
F	15.0	9.0	13.0	9.8	7.4	7.6
Pb	0.13	0.26	0.26	0.39	< 0.10	0.13
Hg	0.02	0.04	0.02	< 0.02	< 0.02	< 0.02
Mo	1.5	1.7	1.17	1.7	1.7	1.5
Ni	0.35	0.35	0.35	0.7	0.30	0.58
Se	< 0.18	0.22	0.50	0.44	< 0.18	< 0.18
U	0.33	0.33	1.2	0.14	0.25	0.25
V	4.1	0.82	4.1	1.80	1.8	0.82
Zn	1.2	1.2	2.5	1.1	0.53	1.1
S2/	0.74	0.73	0.53	0.64	0.60	0.57

1/ Concentration in micrograms per gram.

2/ Concentration percent by weight total sulfur.

TABLE 8

COMPARISON OF SINGLE SAMPLE TO COMPOSITE SAMPLE FROM THREE LOCATIONS WITHIN COAL SEAM. MINE C-II (1975)

Element[1]	Surface		Mid-Seam		Base	
	Comp.	Single	Comp.	Single	Comp.	Single
As	3.5	3.5	< 0.54	3.5	0.76	1.5
Be	2.0	0.38	0.20	0.38	1.0	4.3
Cd	0.13	0.13	< 0.10	0.13	0.13	< 0.10
Cr	2.5	0.67	0.67	1.3	0.67	0.51
Cu	7.7	1.8	1.8	3.6	1.8	1.8
F	25.0	20.0	18.0	18.0	20.0	14.0
Pb	0.19	0.26	0.10	0.11	0.26	0.13
Hg	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Mo	1.7	1.7	1.5	2.9	1.7	1.7
Ni	5.8	1.5	0.7	3.5	0.7	1.3
Se	0.44	0.25	0.58	< 0.18	0.44	< 0.18
U	0.33	0.33	0.33	0.14	0.33	0.16
V	8.2	1.8	1.2	1.8	1.8	1.8
Zn	2.5	0.93	2.5	2.5	2.1	4.7
S[2]	0.97	0.88	0.65	1.13	0.55	0.54

1/ Concentration in micrograms per gram.

2/ Concentration percent by weight total sulfur.

TABLE 9

COMPARISON OF SINGLE SAMPLE TO COMPOSITE SAMPLE FROM THREE LOCATIONS WITHIN COAL SEAM. MINE C-III (1976)

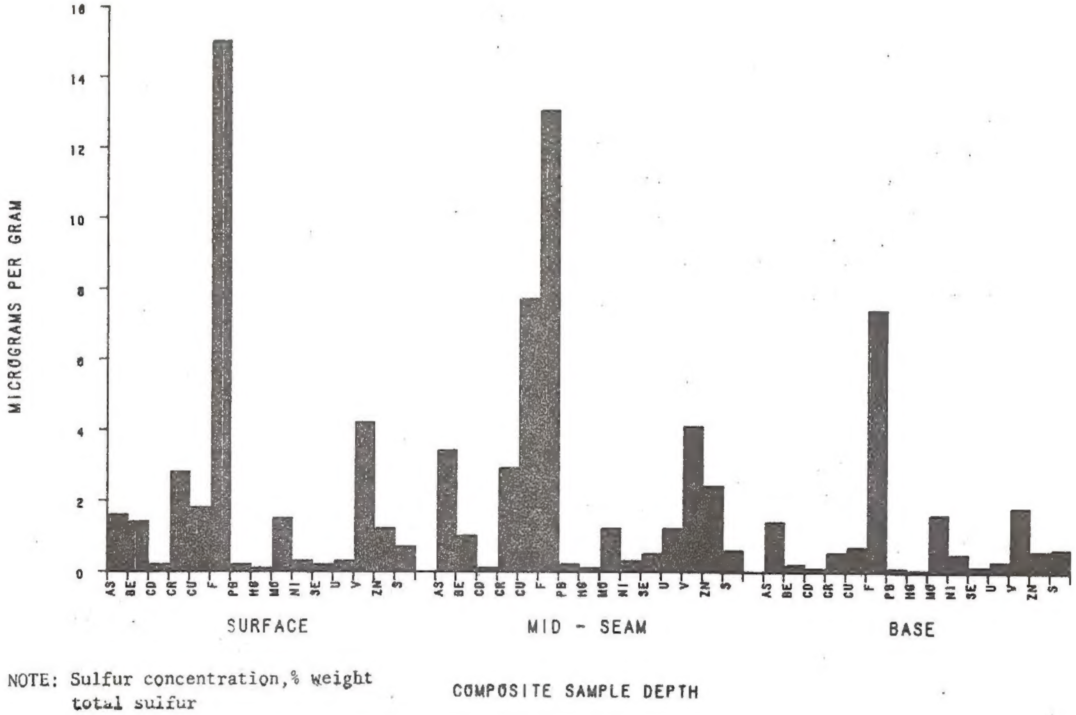
Element[1]	Surface		Mid-Seam		Base	
	Comp.	Single	Comp.	Single	Comp.	Single
As	< 0.54	< 0.54	1.8	1.8	< 0.54	0.59
Be	0.10	< 0.10	0.20	0.10	0.10	< 0.10
Cd	0.11	0.13	0.27	0.13	0.11	0.13
Cr	0.25	0.67	1.0	0.51	0.22	0.58
Cu	0.68	2.7	3.6	1.4	0.60	3.6
F	11.0	11.0	13.0	11.0	13.0	11.0
Pb	0.26	0.19	0.19	0.19	0.10	0.51
Hg	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Mo	1.7	5.8	1.7	1.7	1.2	3.9
Ni	1.5	0.15	0.30	0.7	0.15	0.26
Se	0.18	< 0.18	< 0.18	0.58	< 0.18	0.22
U	0.11	0.28	0.65	0.33	0.14	0.33
V	0.82	4.1	4.1	1.8	0.82	3.1
Zn	2.1	1.2	1.1	12.0	0.30	2.5
S[2]	0.56	0.50	0.63	0.71	0.61	0.68

[1] Concentration in micrograms per gram.

[2] Concentration percent by weight total sulfur.

FIGURE 15

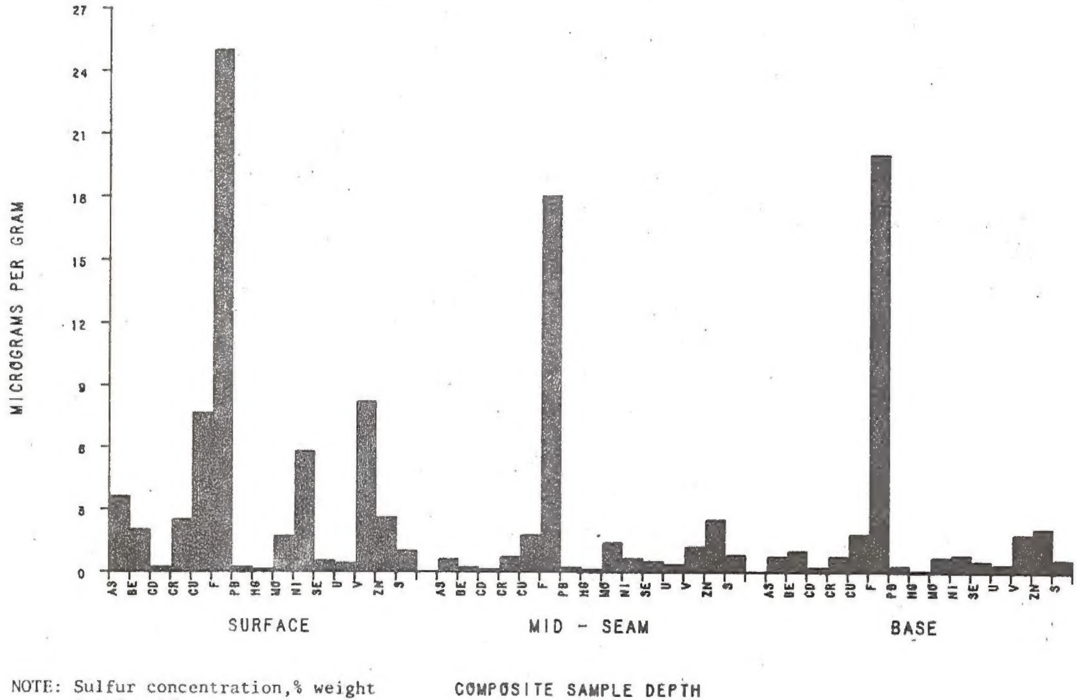
COMPARISON OF TRACE ELEMENT CONCENTRATIONS AT VARIOUS SEAM DEPTHS, MINE C-I



NOTE: Sulfur concentration,% weight
total sulfur

FIGURE 16

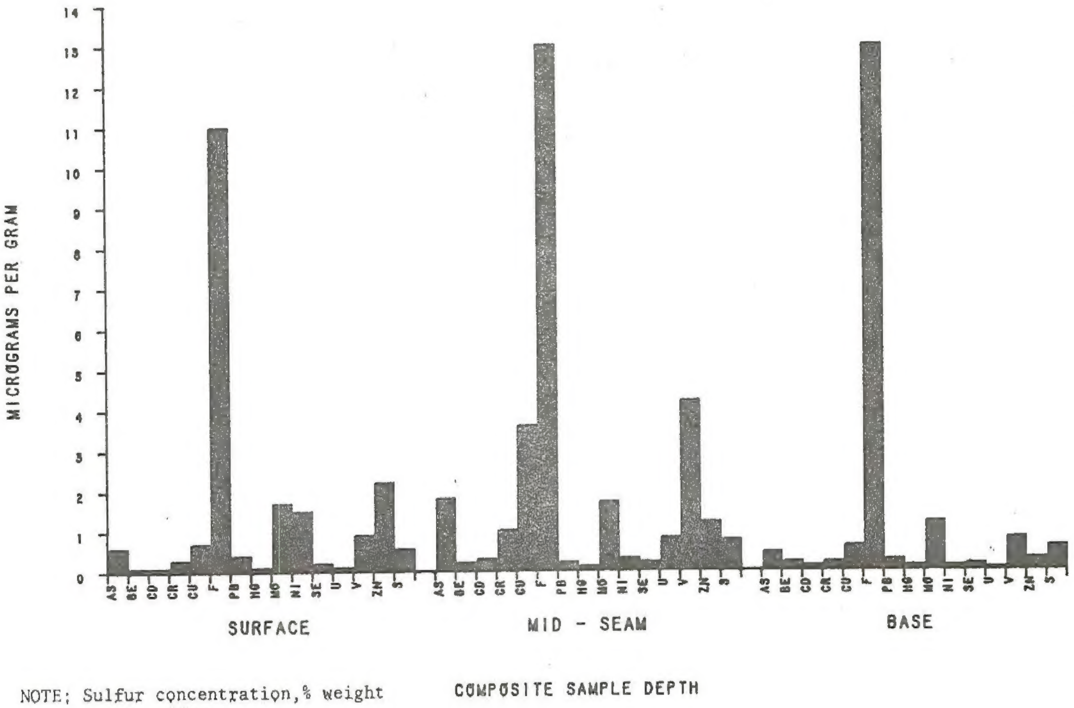
COMPARISON OF TRACE ELEMENT CONCENTRATIONS AT VARIOUS SEAM DEPTHS, MINE C-II



NOTE: Sulfur concentration,% weight
total sulfur

FIGURE 17

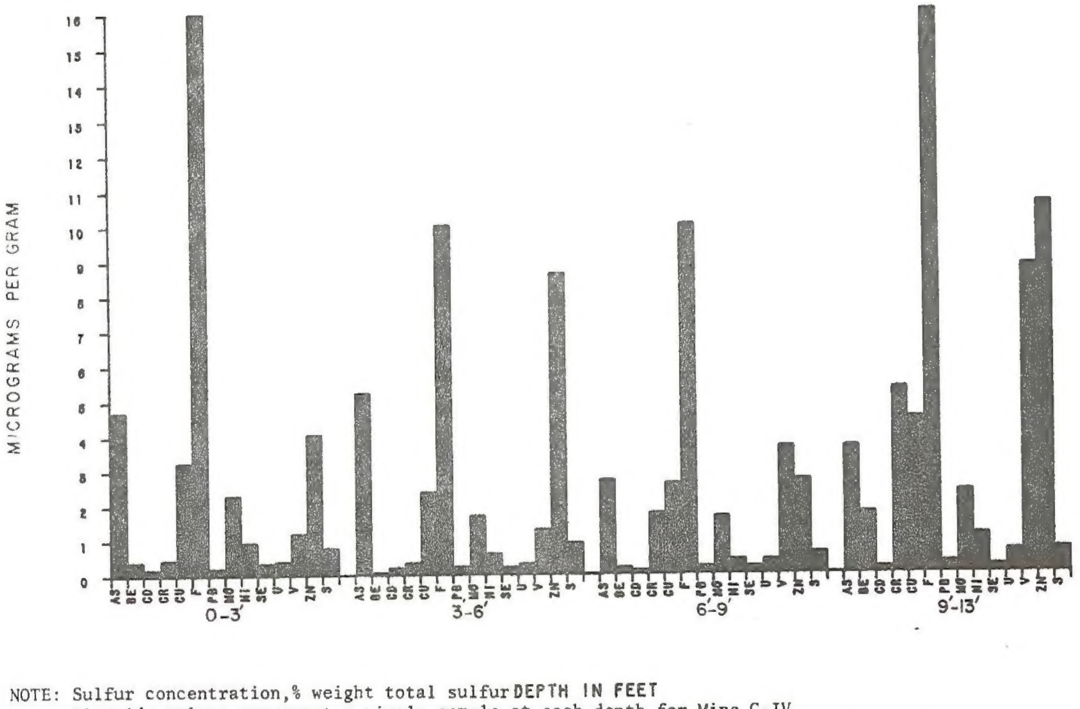
COMPARISON OF TRACE ELEMENT CONCENTRATIONS AT VARIOUS SEAM DEPTHS, MINE C-III



NOTE; Sulfur concentration,% weight
total sulfur

FIGURE 18

COMPARISON OF TRACE ELEMENT CONCENTRATIONS AT VARIOUS SEAM DEPTHS, MINE C-IV



NOTE: Sulfur concentration,% weight total sulfur
Fluoride values represent a single sample at each depth for Mine C-IV

the total number of samples analyzed, it appears that trace element chemical relationships vary from mine to mine and within seam depths within specific mines. Tables 7, 8, and 9, also show that the trace element concentrations vary with seam depth.

The focus of coal sample collection was to obtain data for use in the calculation of trace element emissions for energy conversion facilities in the study area. The emission rates for each trace element were obtained from the mine specific coal concentrations and feed rates for each of the specific energy conversion facilities. An exception in the emission rate calculations involved Facility P-VI which is no longer in operation. The trace element concentrations for the feed coal in this case were arbitrarily selected from the coal data from Mine C-III, as shown in Table 10, since the coal source for Facility P-VI no longer exists.

Soils

The geochemical maps presented in Figures 19a through 19k display the extractable trace element concentrations, as determined by analysis of soil samples in the sampling grid. These maps show chemical distributions for the eleven elements arsenic, beryllium, cadmium, chromium, copper, lead, nickel, sulfur, uranium, vanadium, and zinc. Although the magnitude of these trace elements varies only by a factor of four within the sampling area, there does appear to be a relationship of the higher concentrations to the lignite coal-fired facilities.

TABLE 10

AVERAGE TRACE ELEMENT CONCENTRATIONS FROM ALL COMPOSITE SAMPLES FROM EACH MINE STUDIED

Element[1]	Coal Mine C-I	Coal Mine C-II	Coal Mine C-III	Coal Mine C-IV	Arithmetic Mean
As	2.2	1.60	0.96	3.5	2.07
Be	0.9	1.06	0.17	0.86	0.75
Cd	0.13	0.12	0.16	0.11	0.13
Cr	2.10	1.28	0.49	1.3	1.29
Cu	3.42	3.77	1.63	2.7	2.88
F	11.8	21.0	12.33	17.0	15.53
Pb	0.16	0.18	0.18	0.51	0.26
Hg	0.02	< 0.02	< 0.02	0.09	[3]
Mo	1.46	1.63	1.53	1.9	1.63
Ni	0.33	2.40	0.65	0.35	0.93
Se	0.29	0.49	0.18	0.22	0.30
U	0.59	0.33	0.30	0.65	0.47
V	3.33	3.73	1.91	1.8	2.69
Zn	1.41	2.37	1.17	5.3	2.56
S[2]	0.62	0.72	0.60	0.95	0.72

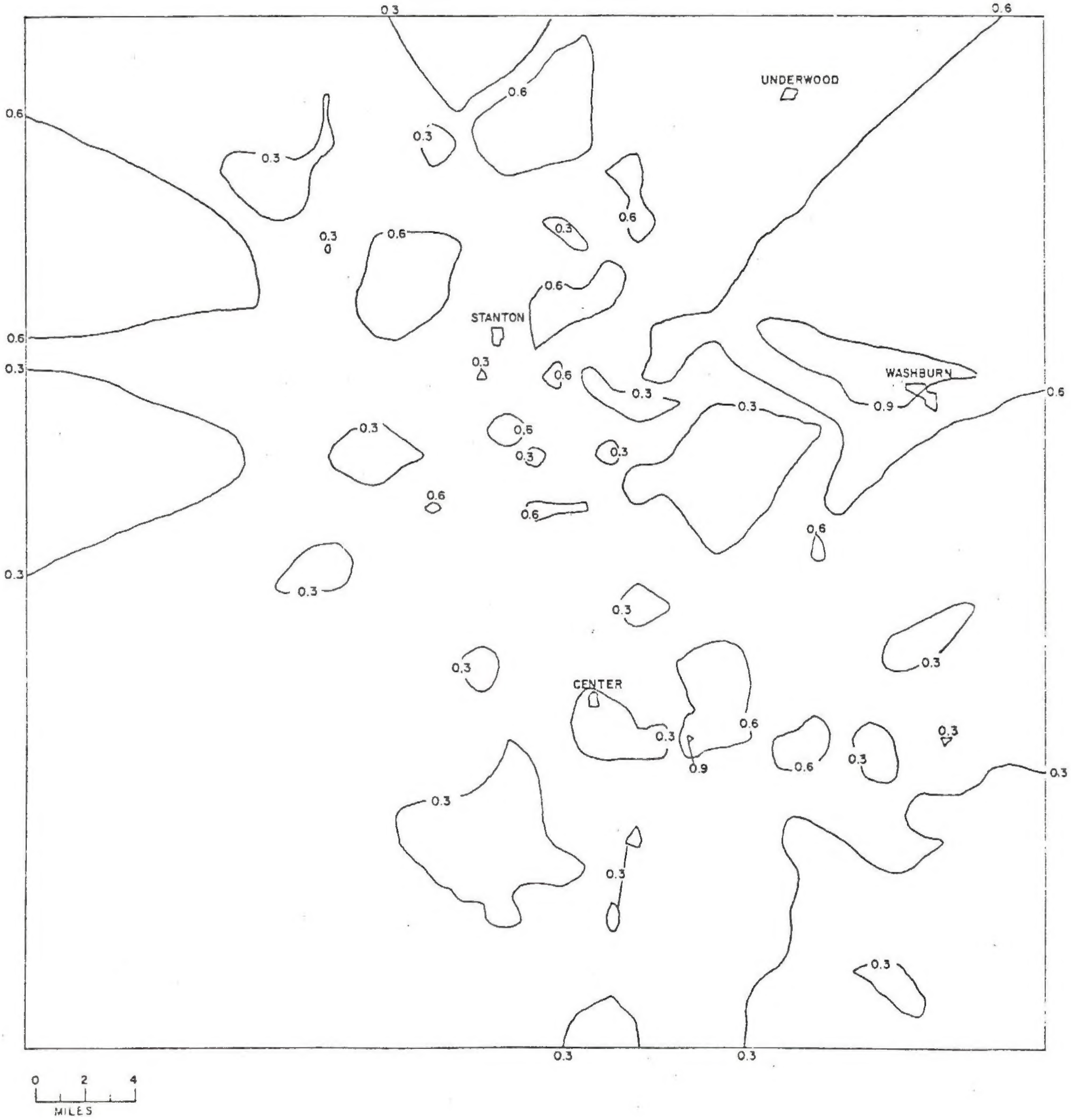
[1] Concentration in micrograms per gram.

[2] Concentration percent by weight.

[3] Greater than 30% of samples less than detectable limit, resulting in arithmetic mean of <0.02.

FIGURE 19a

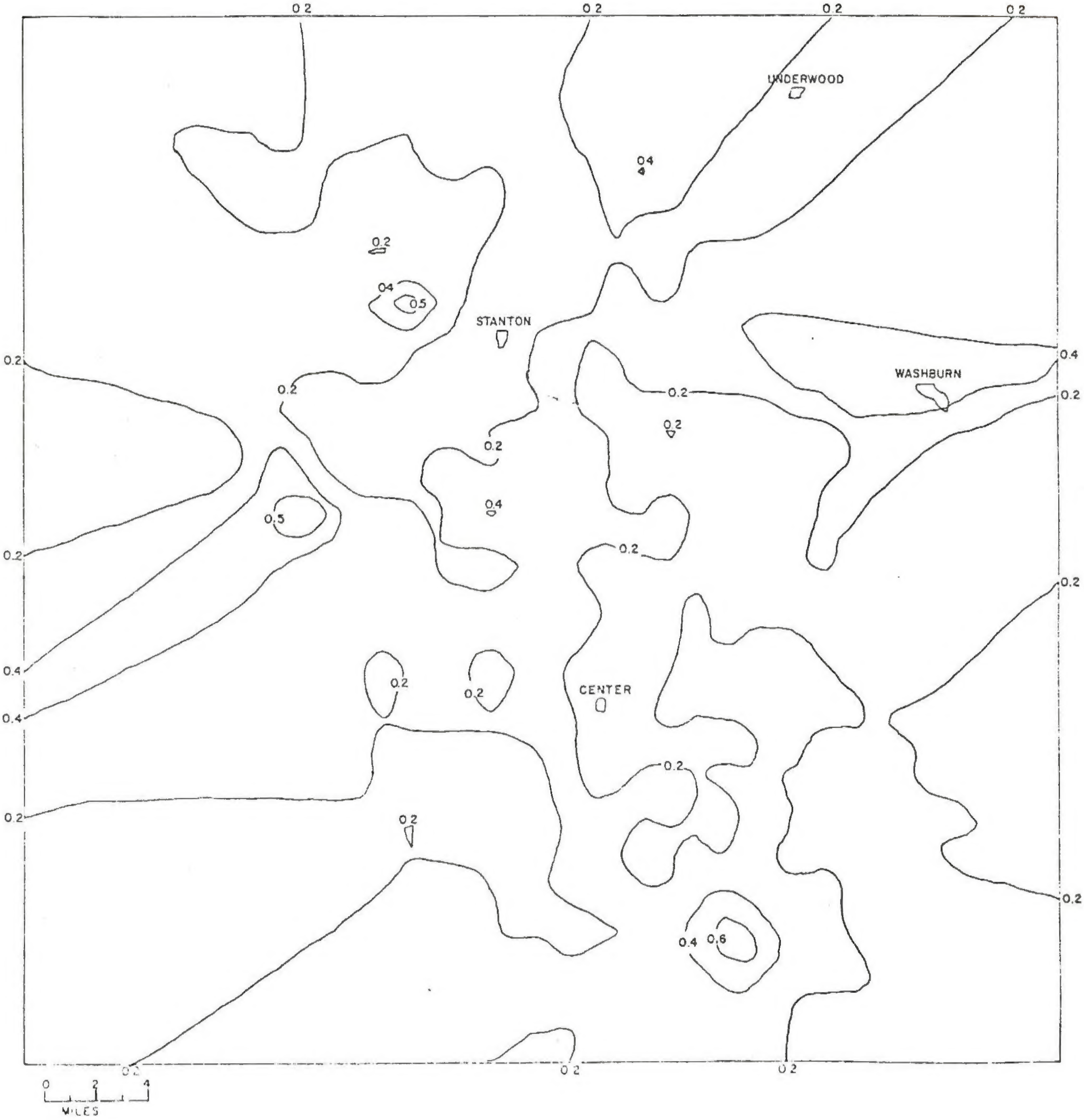
GEOCHEMICAL MAP OF ARSENIC



NOTE: isoline concentrarions in micrograms per gram

FIGURE 19b

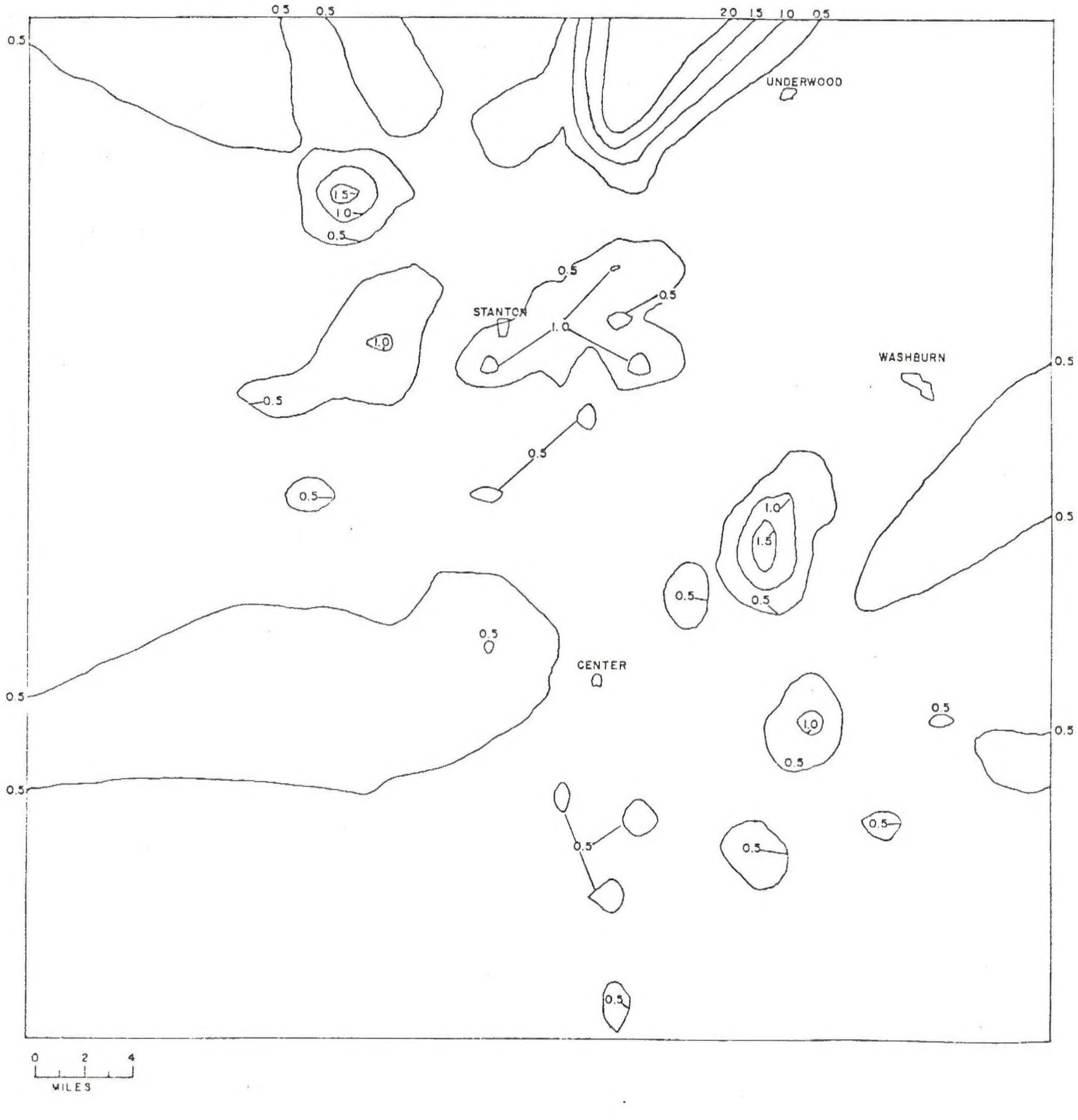
GEOCHEMICAL MAP OF BERYLLIUM



NOTE: isoline concentrations in micrograms per gram

FIGURE 19c

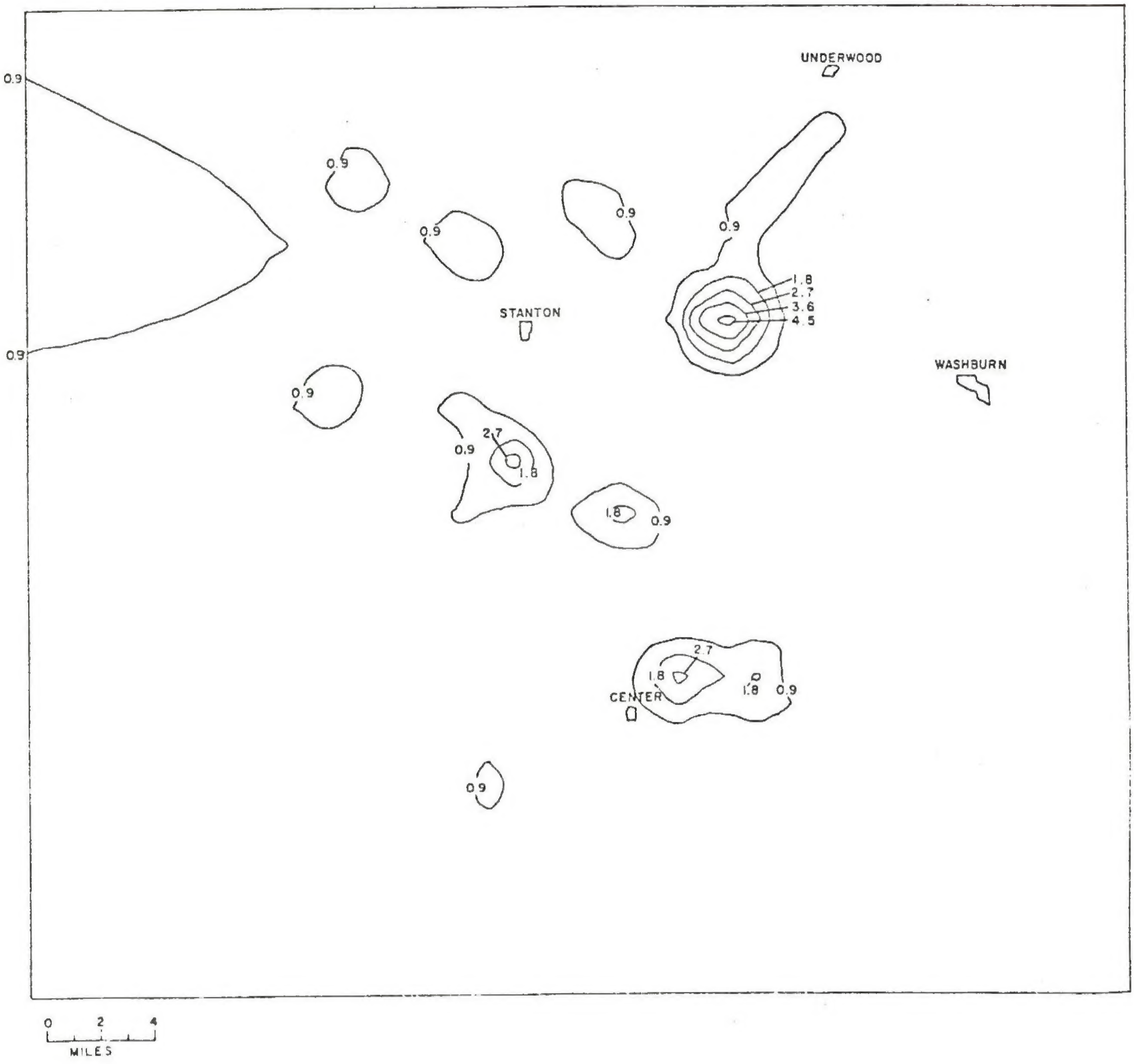
GEOCHEMICAL MAP OF CADMIUM



NOTE: isoline concentrations in micrograms per gram

FIGURE 19d

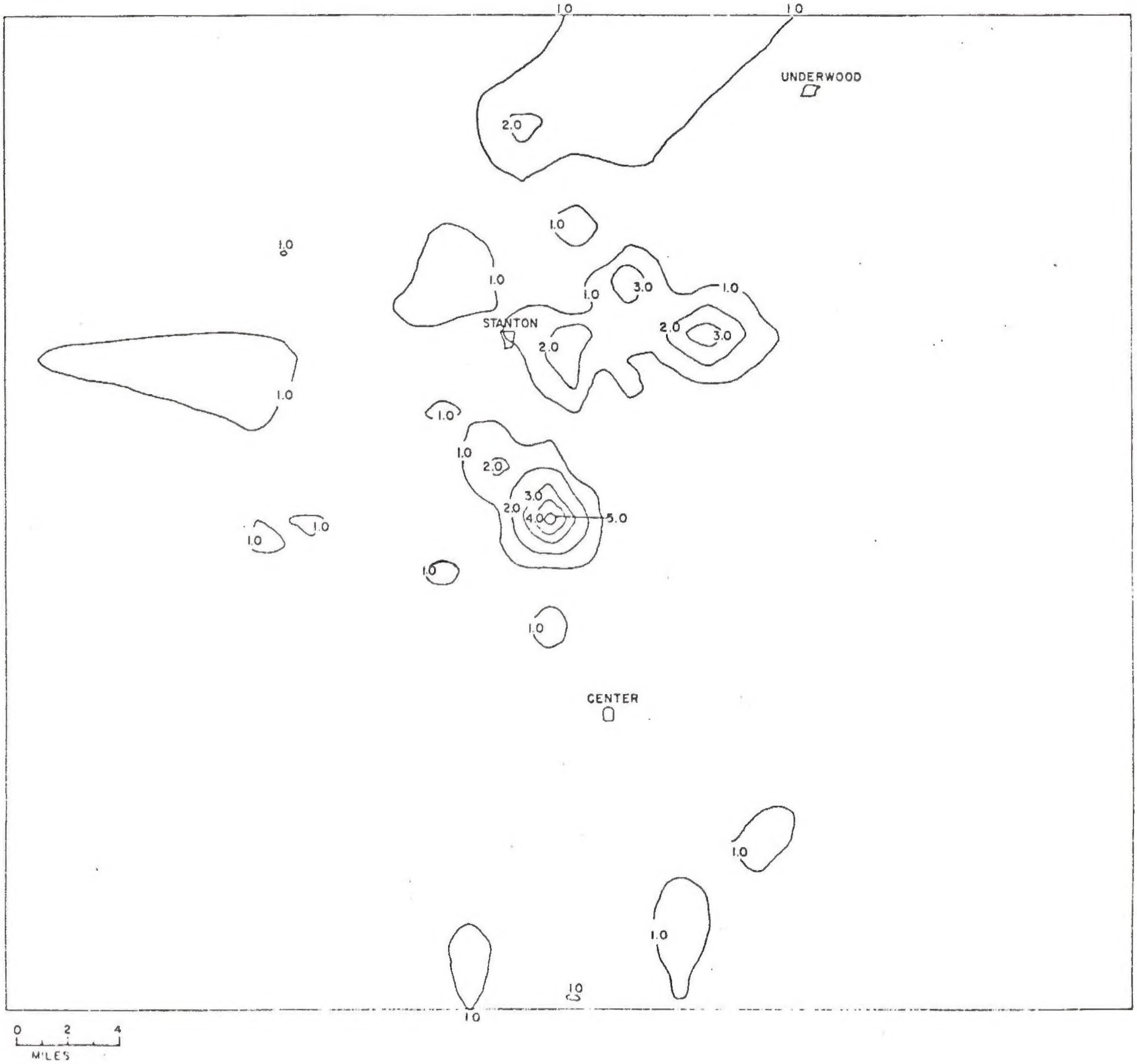
GEOCHEMICAL MAP OF CHROMIUM



NOTE: isoline concentrations in micrograms per gram

FIGURE 19e

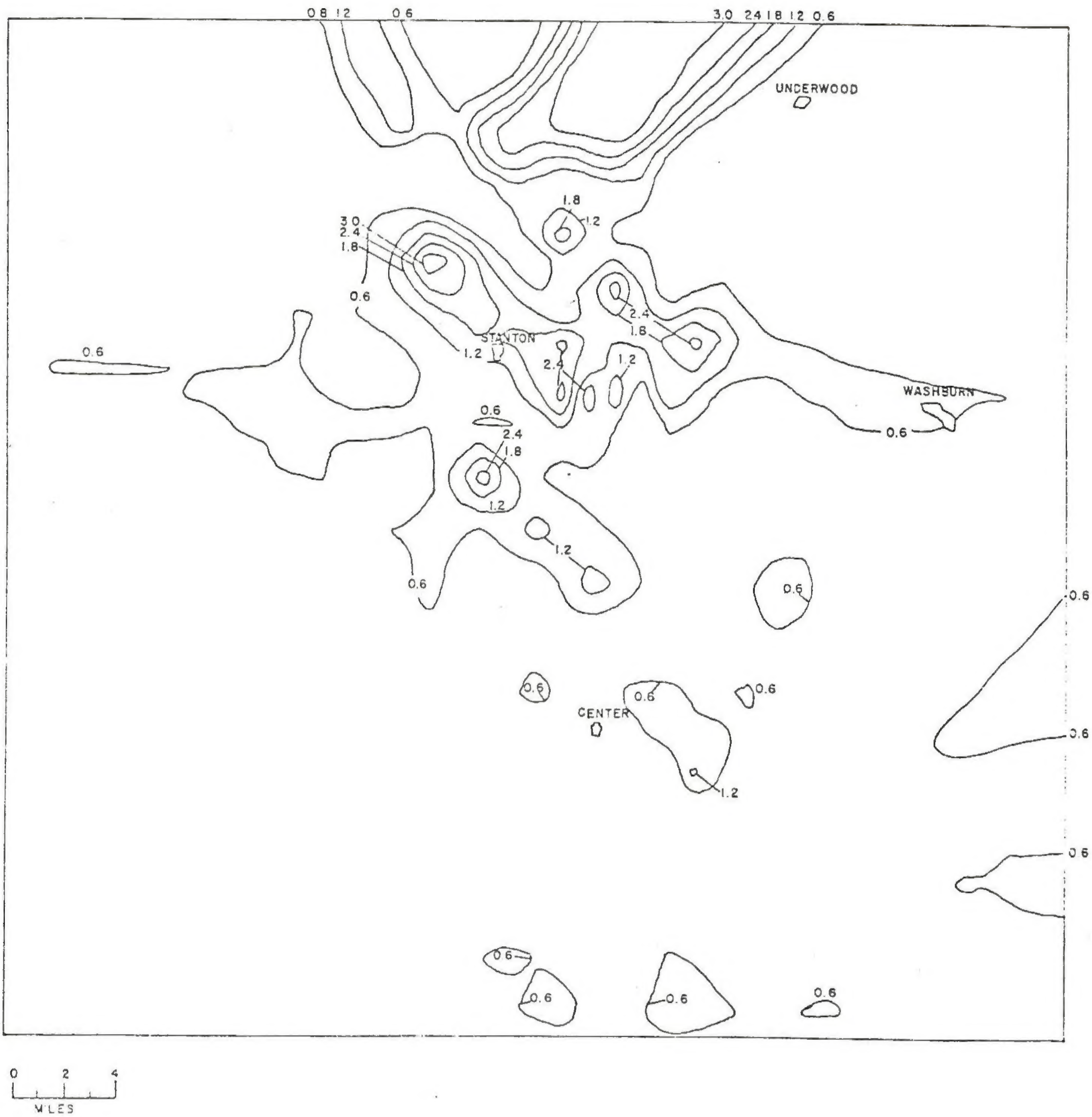
GEOCHEMICAL MAP OF COPPER



NOTE: isoline concentrations in micrograms per gram

FIGURE 19f

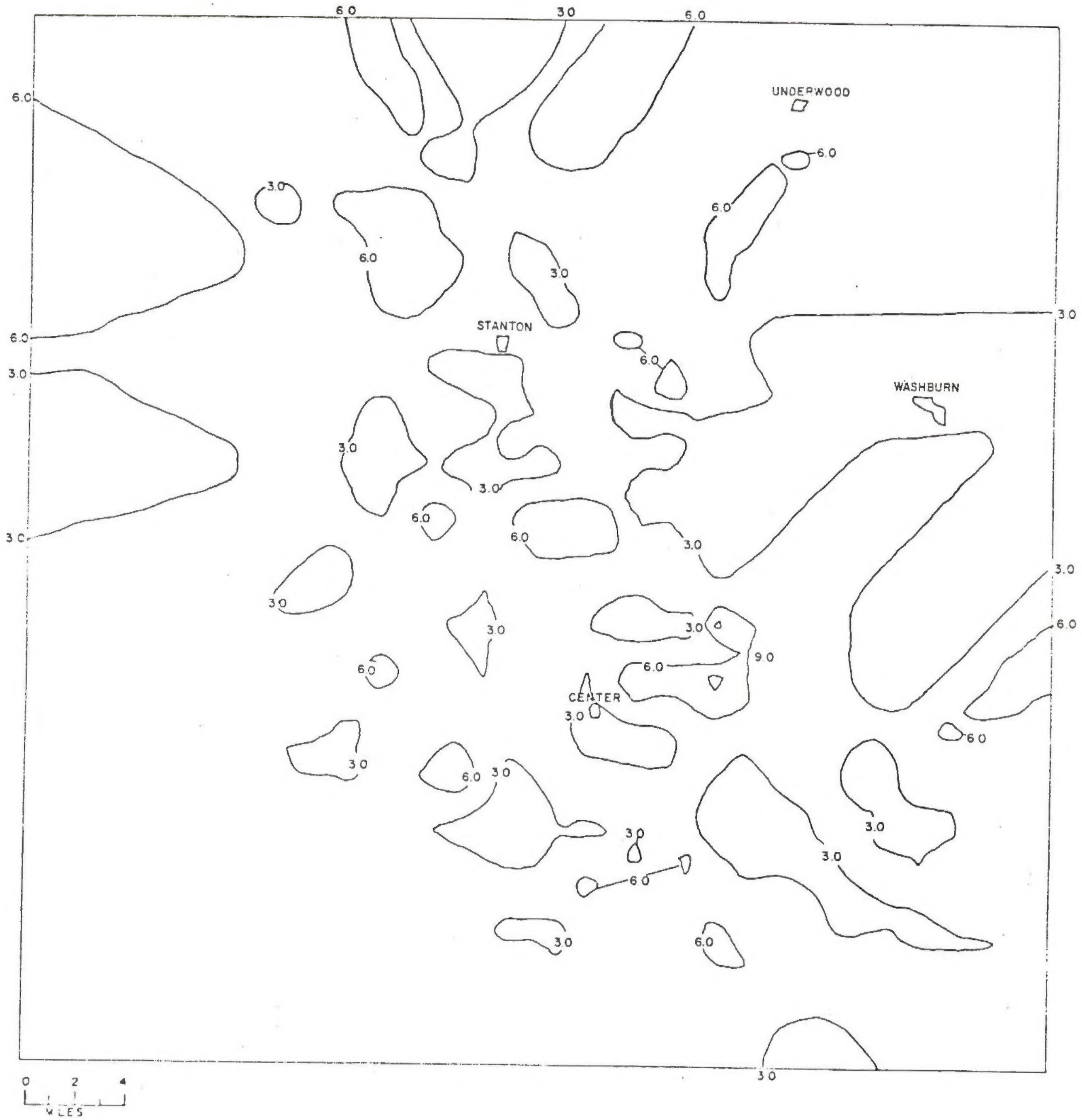
GEOCHEMICAL MAP OF LEAD



NOTE: isoline concentrations in micrograms per gram

FIGURE 19g

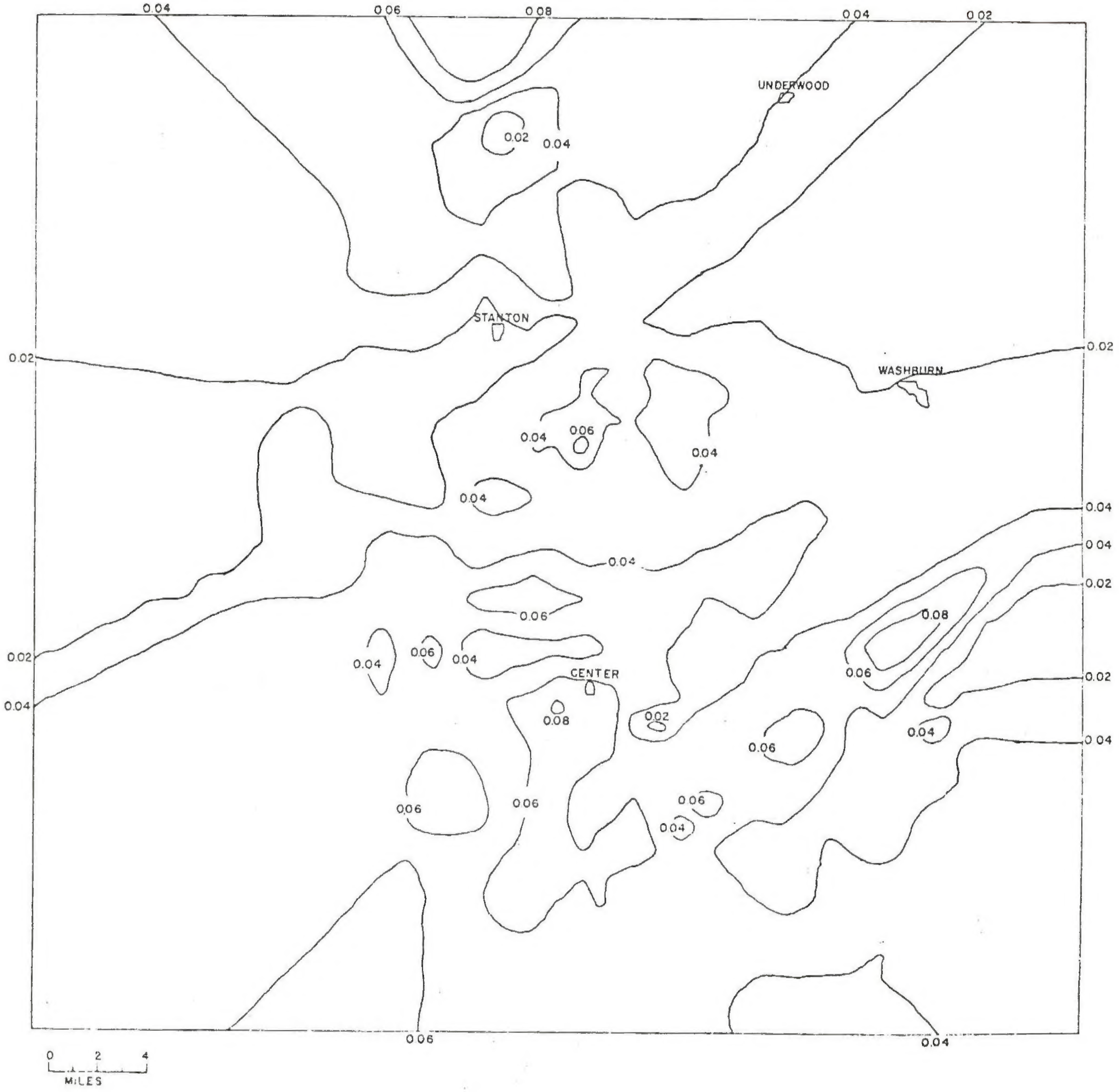
GEOCHEMICAL MAP OF NICKEL



NOTE: isoline concentrations in micrograms per gram

FIGURE 19h

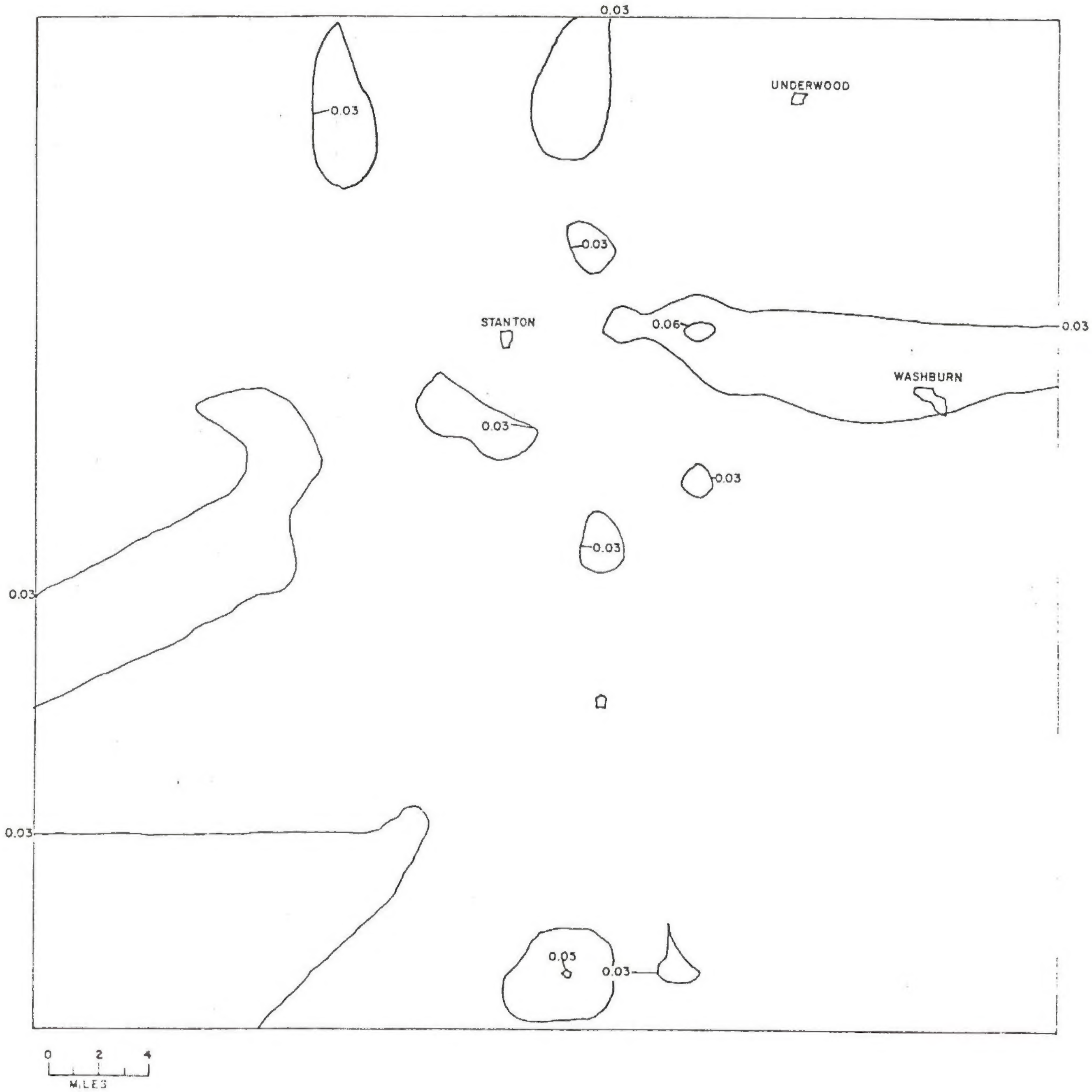
GEOCHEMICAL MAP OF SULFUR



NOTE: isoline concentrations as total sulfur, % weight

FIGURE 19i

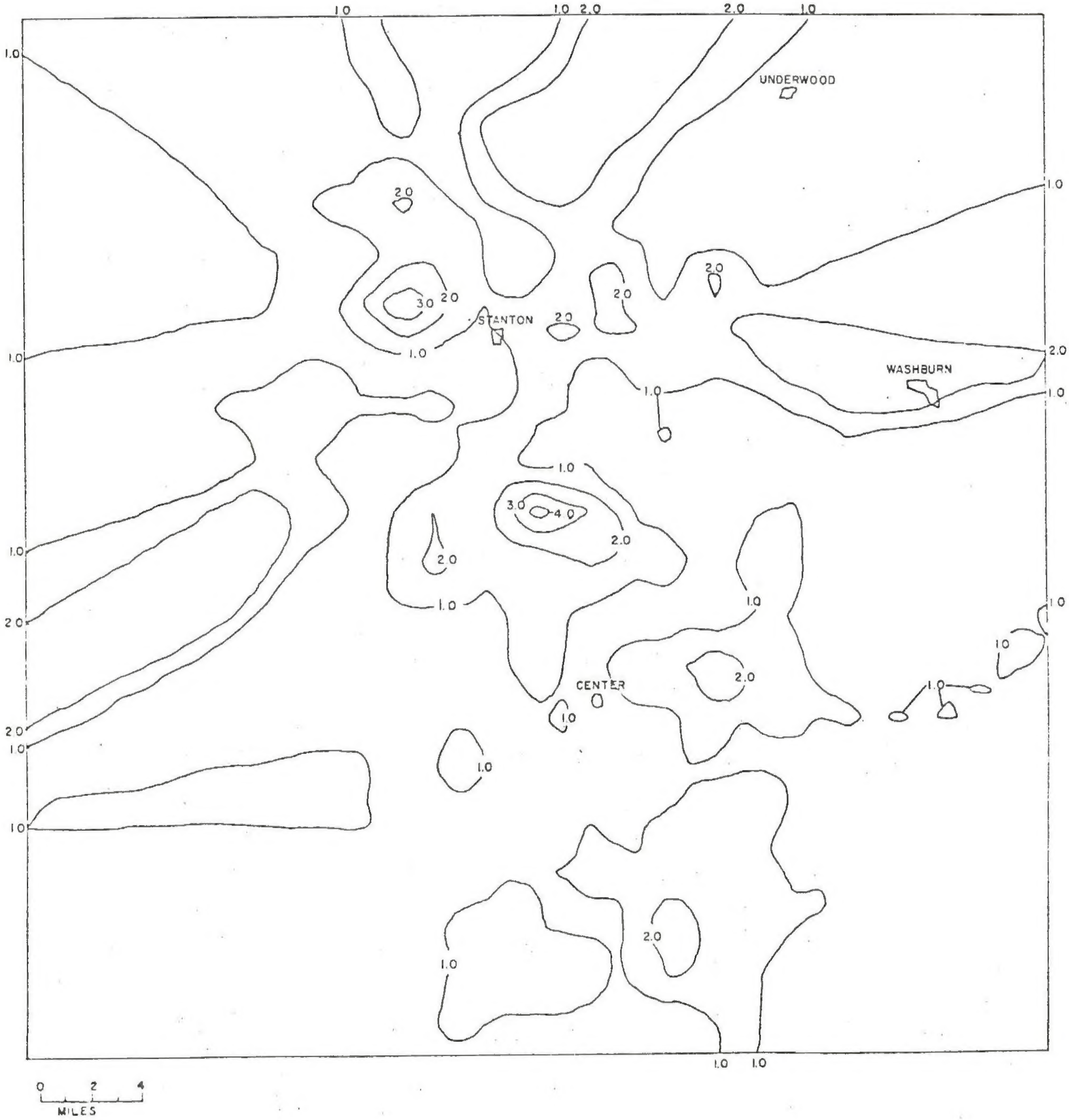
GEOCHEMICAL MAP OF URANIUM



NOTE: isoline concentrations in micrograms per gram

FIGURE 19j

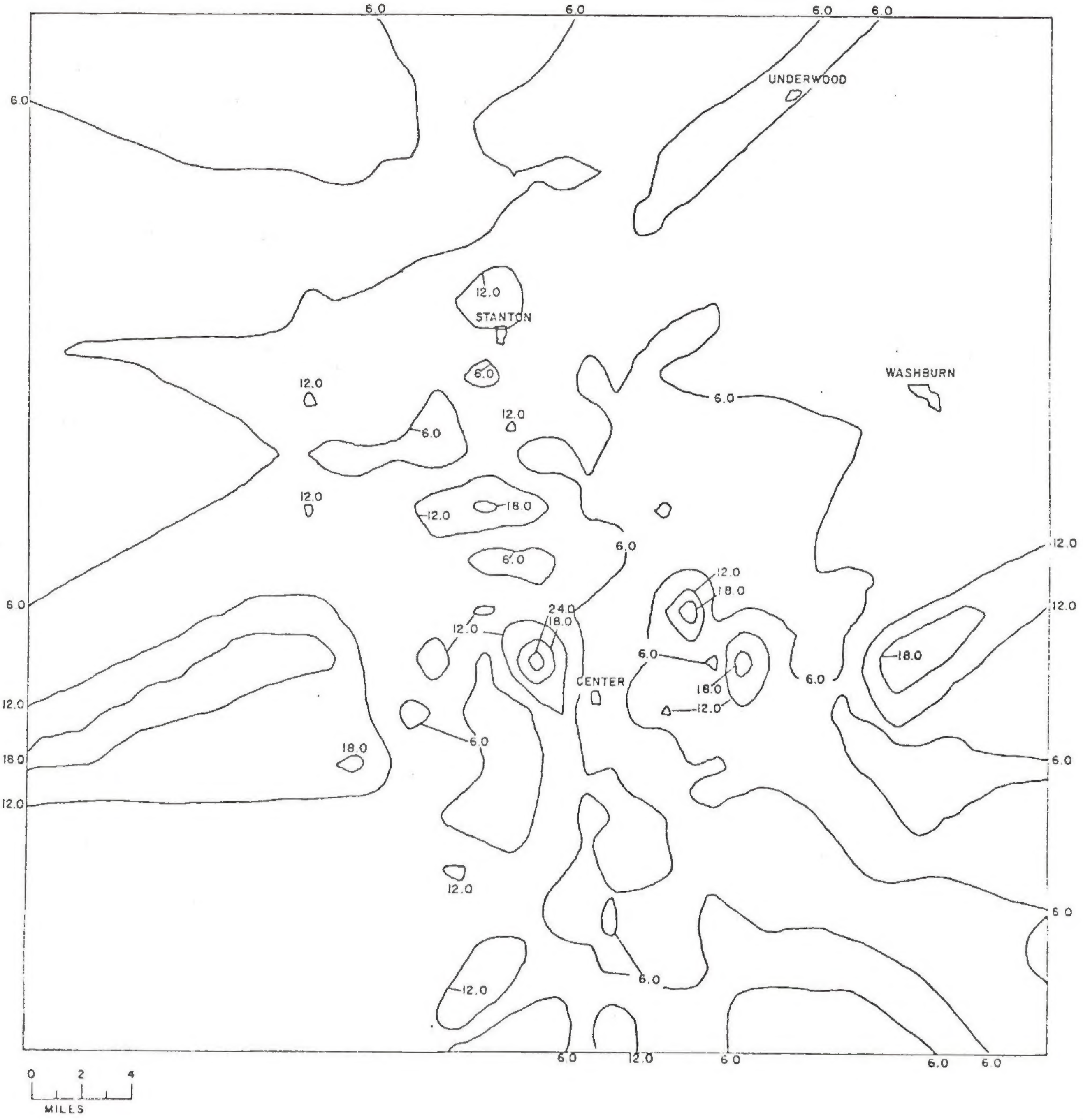
GEOCHEMICAL MAP OF VANADIUM



NOTE: isoline concentrations in micrograms per gram

FIGURE 19k

GEOCHEMICAL MAP OF ZINC



NOTE: isoline concentrations in micrograms per gram

Positive correlation of the higher trace element concentrations shown on these maps to the integrated emissions from the respective facilities could not be undertaken within the limited scope of this phase of study.

Intensifying the soil sampling grid around the respective facilities, (Figure 9a), and comparisons with specific trace element deposition patterns over the study area will be considered in the next phase of this study. Nevertheless it is possible that the underlying parent soil material and various geological formations of the study area may account for the geochemical variations displayed on these maps. In any event the concentration variations could not be definitely attributed in this phase of study to existing operating energy conversion facilities in the study area.

The evaluation of trace elements in soils involved the comparison of trace elements in cultivated soil to those in undisturbed soils. The purpose of this comparison was to assess the influence of agricultural activities on trace element concentrations. The arithmetic mean concentrations for samples of cultivated field and corresponding undisturbed soils are presented in Table 11. One standard deviation of sample variance was calculated for each element for all cultivated field soil samples. A statistically significant difference between the undisturbed and cultivated soils was determined to occur when the difference between the arithmetic mean of the

TABLE 11

RELATIONSHIP OF CULTIVATED FIELD SOIL TRACE ELEMENT CONCENTRATIONS TO UNDISTURBED SOIL CONCENTRATIONS

Element	Undisturbed Soils[1]	Cultivated Soils[1]	Standard Deviation Cultivated Soils
Arsenic	0.49	0.43	±0.16
Beryllium	0.25	0.24	±0.06
Cadmium	0.54	0.40	±0.14
Copper	0.79	0.70	±0.30
Chromium	0.60	0.34	±0.19
Nickel	4.8	5.0	±1.62
Vanadium	1.26	0.79	±0.20
Zinc	7.6	3.6	±1.3

[1] Arithmetic mean of extractable concentrations in micrograms/gram

undisturbed soil and the corresponding cultivated soil was more than one standard deviation. A signficant difference in concentrations can be observed to exist only between the soil groups for the elements chromium, vanadium, and zinc.

Data is presented in the analysis for only eight of the fifteen elements under consideration. A major portion of analytical data for the elements lead, mercury, molybdenum, selenium, and uranium, were found to be at concentration values below the quantifiable detectable limit. Also, no analytical data for sulfur and fluoride is available for cultivated field soil samples. For the elements arsenic, beryllium, cadmium, copper, and nickel, the observed differences between the two corresponding types of samples were not considered significant.

Chromium, vanadium, and zinc concentrations in undisturbed soils, are greater than the cultivated field soil concentrations plus one standard deviation. The influence of agricultural activities, such as tillage, crop types, crop rotation, and fertilizer practices cannot be ingnored in evaluating trace element anomalies of significance relative to the "natural" geochemical trace element levels observed in undisturbed soils.

Cultivated soils were also collected as profile samples to determine whether significant geochemical variation in element concentrations exist with increasing depth in the upper level of root zones for food and forage crops. Data concerning trace element concentrations in these profile samples is shown in Table 12. This data demonstrates insignificant concentration differences at the depth ranges presented.

Thirty-five soil profile samples were collected from undisturbed soils for assessment of the soil trace element concentrations through three depth ranges. The arithmetic mean concentration for each element for various sampling depths are presented in Table 13. Only eight of the fifteen elements in this study are presented in this table. The arithmetic mean concentrations for mercury, lead, uranium, molybdenum, and selenium were not calculated since greater than 30 percent of the analytical values obtained were less than the quantifiable detectable limit. Also, complete profile analysis for fluoride and sulfur content was not performed in the course of this study. From Table 13, it can be observed that all of the trace elements were found to have a uniform concentration in the depth range from 0 to 9 inches.

Deposition Patterns for Specific Facilities

Trace element deposition patterns for each of the six facilities were computer projected using the facility and coal data shown on Tables 5 and 10, respectively. Feed coals for facilities P-I, P-II, P-III, P-IV, and P-V were Mines C-IV, C-III, C-III, C-II, and C-I, respectively. The joint frequency wind data used for this analysis was derived from wind observations taken by the the National Weather Service Office at Bismarck, North

TABLE 12

ELEMENT CONCENTRATIONS AT TWO DEPTH RANGES FOR CULTIVATED FIELD SOIL SAMPLES

Element	Depth Range and Concentration[1/] 0-4"	4-8"	Standard Deviation 0-4" Samples
Arsenic	0.43	0.39	±0.17
Beryllium	0.25	0.25	±0.08
Cadmium	0.38	0.35	±0.14
Chromium	0.37	0.37	±0.17
Copper	0.70	0.62	±0.31
Nickel	5.0	4.15	±1.57
Vanadium	0.79	1.12	±0.21
Zinc	3.61	3.11	±1.30

[1/] Arithmetic mean of extractable concentrations in micrograms per gram.

TABLE 13

TRACE ELEMENT CONCENTRATIONS IN PROFILE SAMPLES OF UNDISTURBED SOILS (1975)

Element	Depth[1] 0-3"	3-6"	6-9"	Standard Deviation 0-3" Samples
Arsenic	0.41	0.39	0.38	±0.16
Beryllium	0.20	0.22	0.21	±0.13
Cadmium	0.38	0.36	0.41	±0.25
Chromium	0.56	0.40	0.50	±0.41
Copper	0.69	0.76	0.97	±0.53
Nickel	4.89	3.62	4.93	±5.90
Vanadium	1.25	0.94	1.11	±0.97
Zinc	6.83	3.52	3.45	±4.48

[1] Arithmetic mean of extractable concentrations in micrograms per gram.

Dakota and represents an annual climatic average condition for years 1948 to 1974.

The shape of a deposition pattern around a facility stack is primarily dependent upon the frequency of occurrences of wind direction and speed, and stack height. The magnitude of deposition at a given location depends upon the trace element emission rate from the stack, particle size of the stack effluent, and the downstream distance of the location from the stack. Figures 20 and 21 display annual deposition patterns for selenium from Plants P-V and P-VI, respectively.

The choice of selenium for this analysis was arbitrary, and does not imply that this element is more or less environmentally hazardous. Such an analysis remains for subsequent study efforts. Deposition patterns for other trace element emissions from these two facilities would have the same shapes; the magnitudes can be obtained by dividing the emission rates for these elements from equation (7) by the emission rate for selenium as presented in the Methods section of this report.

In Figure 20, the maximum deposition occurs to the east-southeast through southeast of the facility stack. This is caused by the higher (relative to other directions) occurrence of winds from the northwest. A secondary maximum anomaly (regions of high deposition relative to surrounding regions) in Figure 20 occurs northward of the facility stacks. These

FIGURE 20

SELENIUM DEPOSITION FOR FACILITY P-V IN UNITS OF $\mu g/m^2/yr$

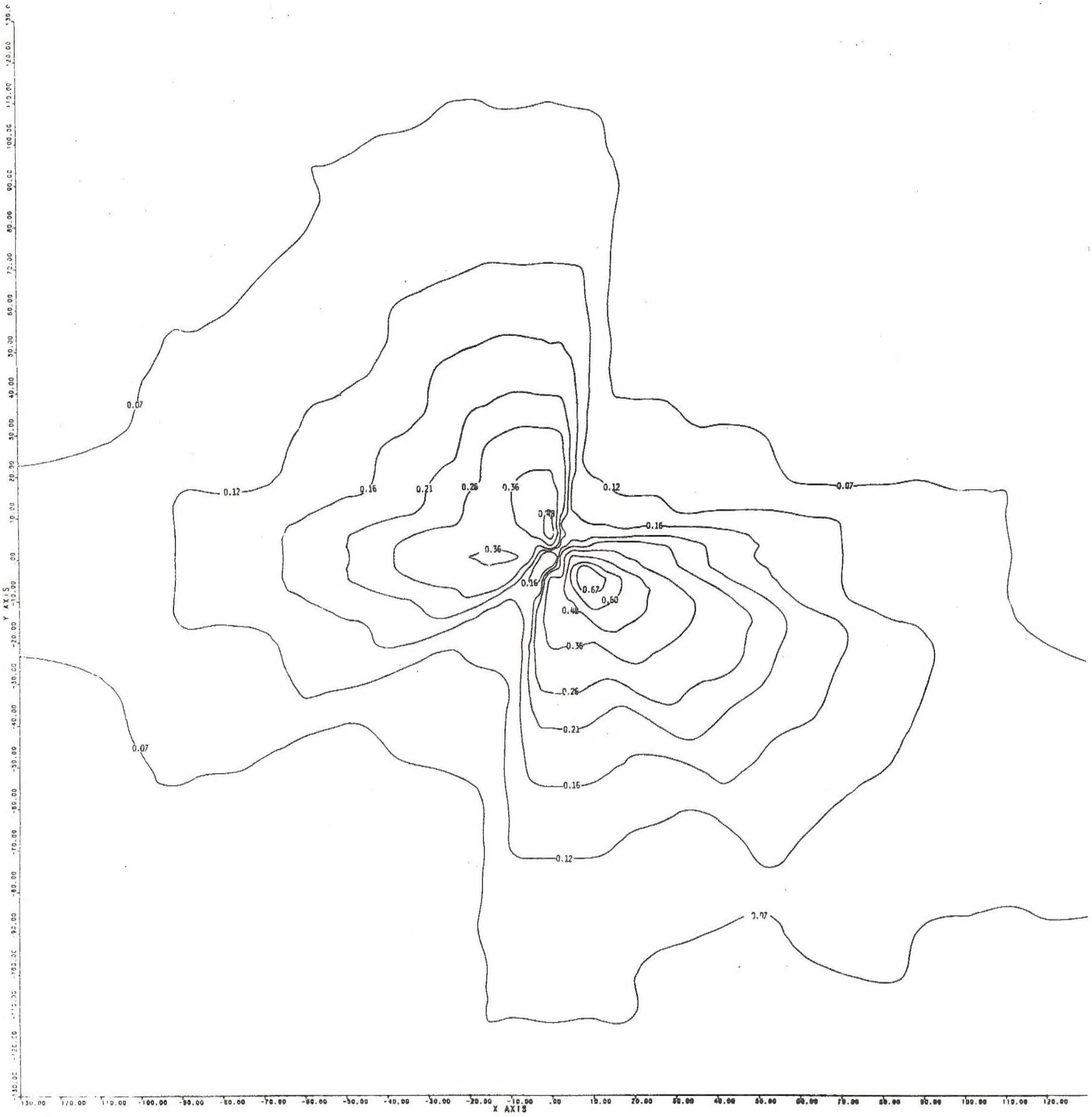
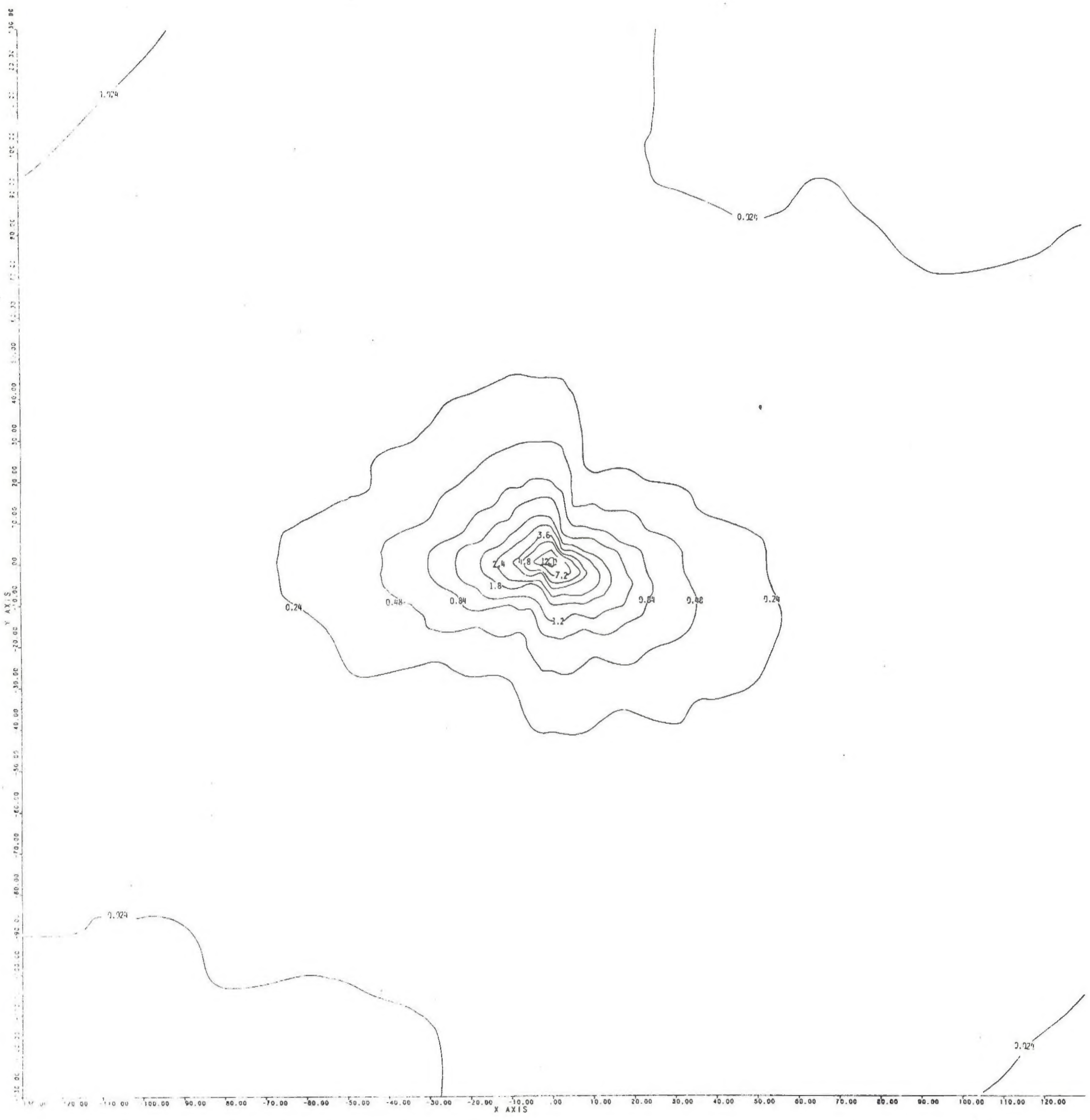


FIGURE 21

SELENIUM DEPOSITION FOR FACILITY P-VI IN UNITS OF μg/m²/yr



anomalies are not as evident in Figure 21, although the same wind data was used; the reason is due to a much shorter stack and larger diameter of emission particles for Facility P-VI.

Facility P-V can be characterized as a "contemporary" facility in that its features are representative of recent coal-fired facility design and operation. Facility P-VI can be characterized as a "historic" facility in that its features are representative of early coal-fired power plant design and operation. Table 14 demonstrates a qualitative comparison of "contemporary" and "historic" facilities.

The numerical modeling analysis has identified a significant facility performance difference. This difference is a reduction in deposition with improved emission control systems. The improvements in facility design and operation are shown by this analysis to have reduced the ratios of deposition per unit of power generation by a factor of about 1000. In the relative comparison of facility designs, historic facility designs are those of the mid-1920's, while contemporary designs represent the engineering technology of the mid-1960's.

A "typical" design schematic for the inlet and outlet stream flows of new facilities of the design scheme of the mid-1970's is shown in Figures 22a and 22b. The marked advances in new facility design and emission control equipment technology, when compared to the older facility design schematics, is quite

TABLE 14

A RELATIVE COMPARISON OF TWO FACILITY DESIGNS

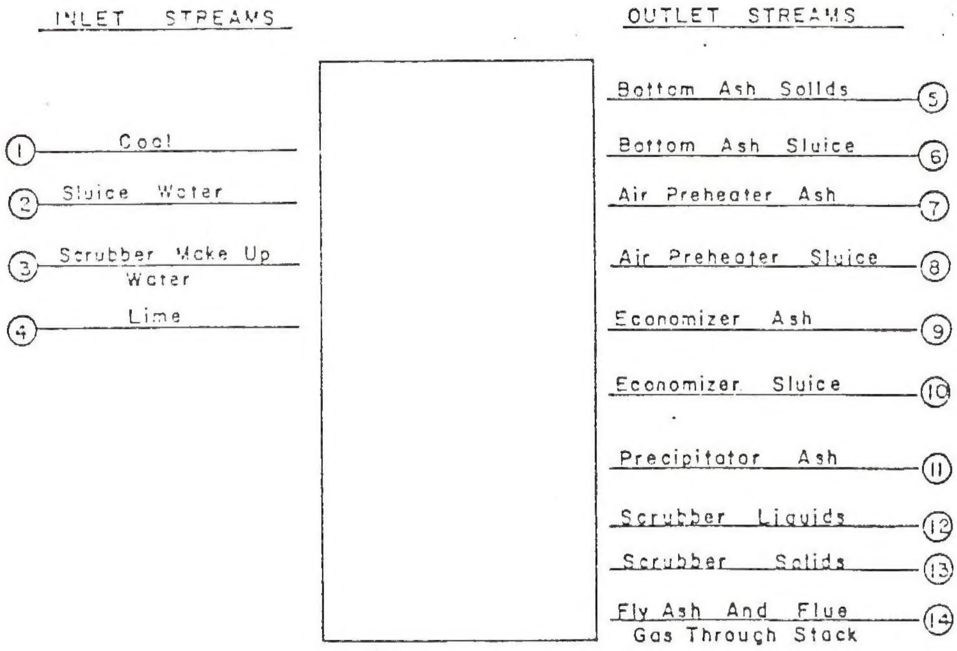
DESIGN	HISTORIC[1] DESIGN	CONTEMPORARY[2] DESIGN	APPROXIMATE DIFFERENCE
Stack height	low	high	factor of two
Coal feed rate	low	high	factor of fifteen
Emissions control	no	yes	
Power generation	low	high	factor of twenty
Point of maximum deposition	less than 5 kilometers from the stack	more than 10 kilometers from the stack	
Maximum annual deposition	very high	low	factor of fifty
Maximum annual deposition per unit of power generation	very high	low	factor of one thousand

1/ Approximate design period 1920

2/ Approximate design period 1960

FIGURE 22a

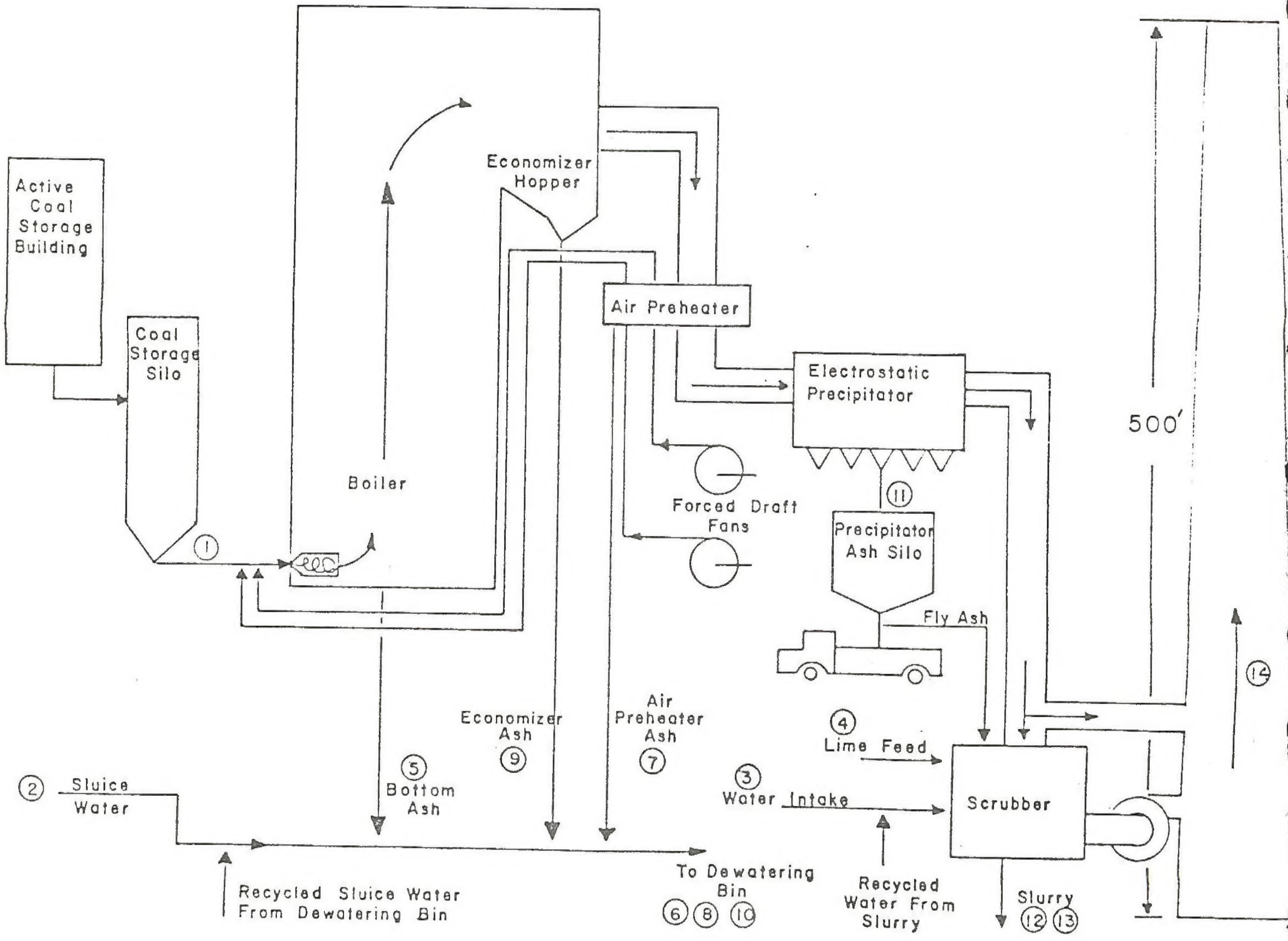
INLET AND OUTLET STREAMS TYPICAL OF NEW AND PROPOSED FACILITIES IN THE STUDY AREA



SOURCE: Radian Corporation 1975

FIGURE 22b

TYPICAL DESIGN OF NEW AND PROPOSED FACILITIES IN THE STUDY AREA



SOURCE: Radian Corporation 1975

evident. In general, the new facilities have incorporated within their design schemes electrostatic precipitators for fly ash control and lime supplemented and other scrubber systems for sulfur dioxide control.

A composite trace element deposition pattern for all facilities in the study area was also performed by computer analysis. The surface deposition in the study area becomes an accumulation of the depositions from each of the six facilities influencing the area. An assessment of the net impact can be made from an area-wide analysis which includes all of these facilities.

Figure 23 displays the numerical dispersion model projections of annual trace element deposition of selenium for those plants currently operating (P-I, P-II, P-III, P-IV, and P-V); while Figure 24 also includes Facility P-VI which has not operated since 1969. These figures were obtained by placing the individual plant deposition patterns in proper geographic perspective and integrating the individual patterns into an accumulation of deposition for the area.

In Figures 20 and 21, anomalies occur near the facility stack, north of the stack, or southeast of the stack. The anomaly north of Facility P-I and southeast of Facilities P-III and P-IV in Figure 23 is caused by the interaction of these three facilities. As observed by comparison of Figures 20 and 21, the projected deposition for Facility P-VI is nearly ten orders of

FIGURE 23

COMPOSITE SELENIUM DEPOSITION WITHIN THE STUDY AREA FROM FACILITIES P-I, P-II, P-III, P-IV AND P-V IN $\mu g/m^2/yr$

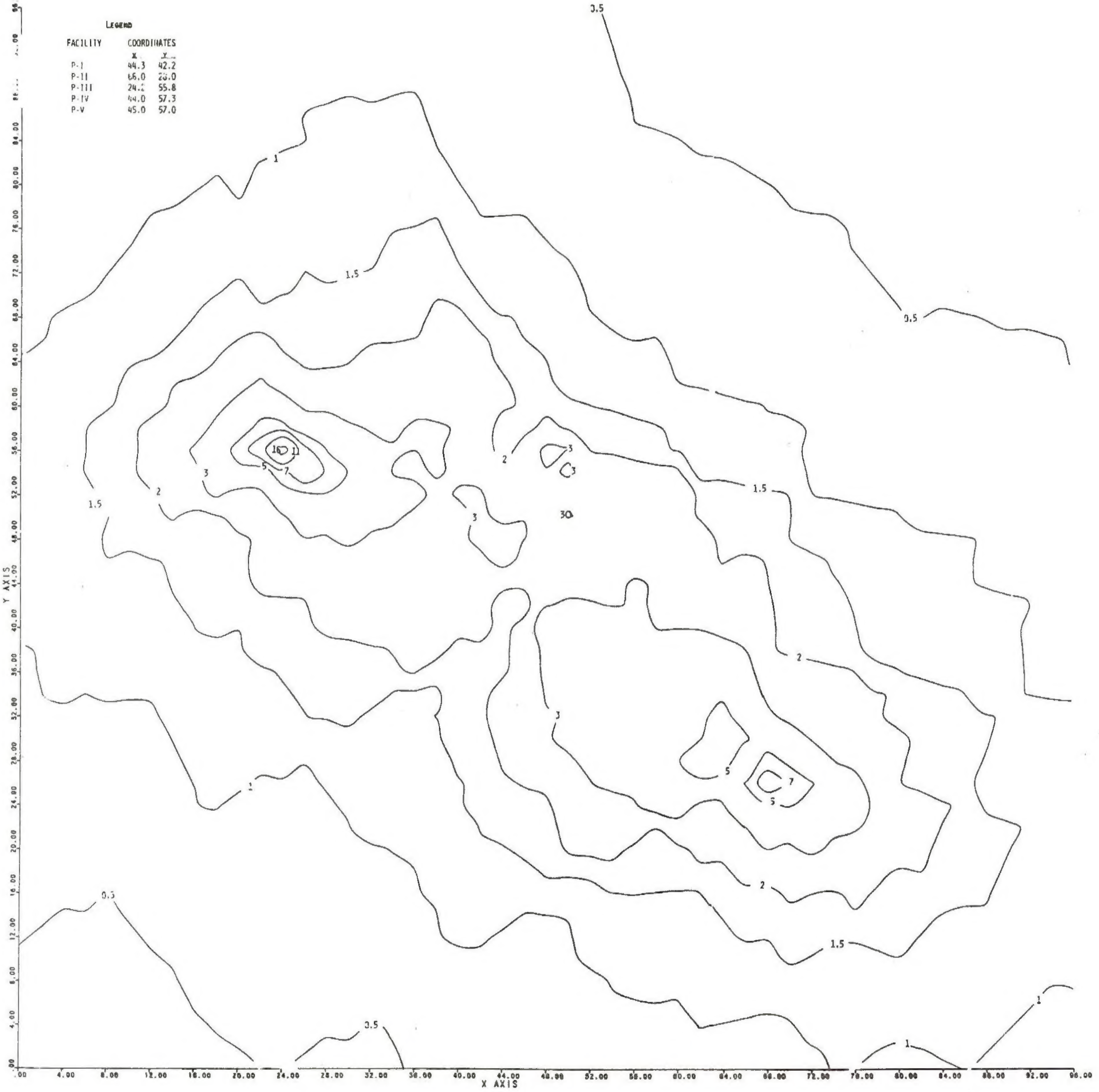
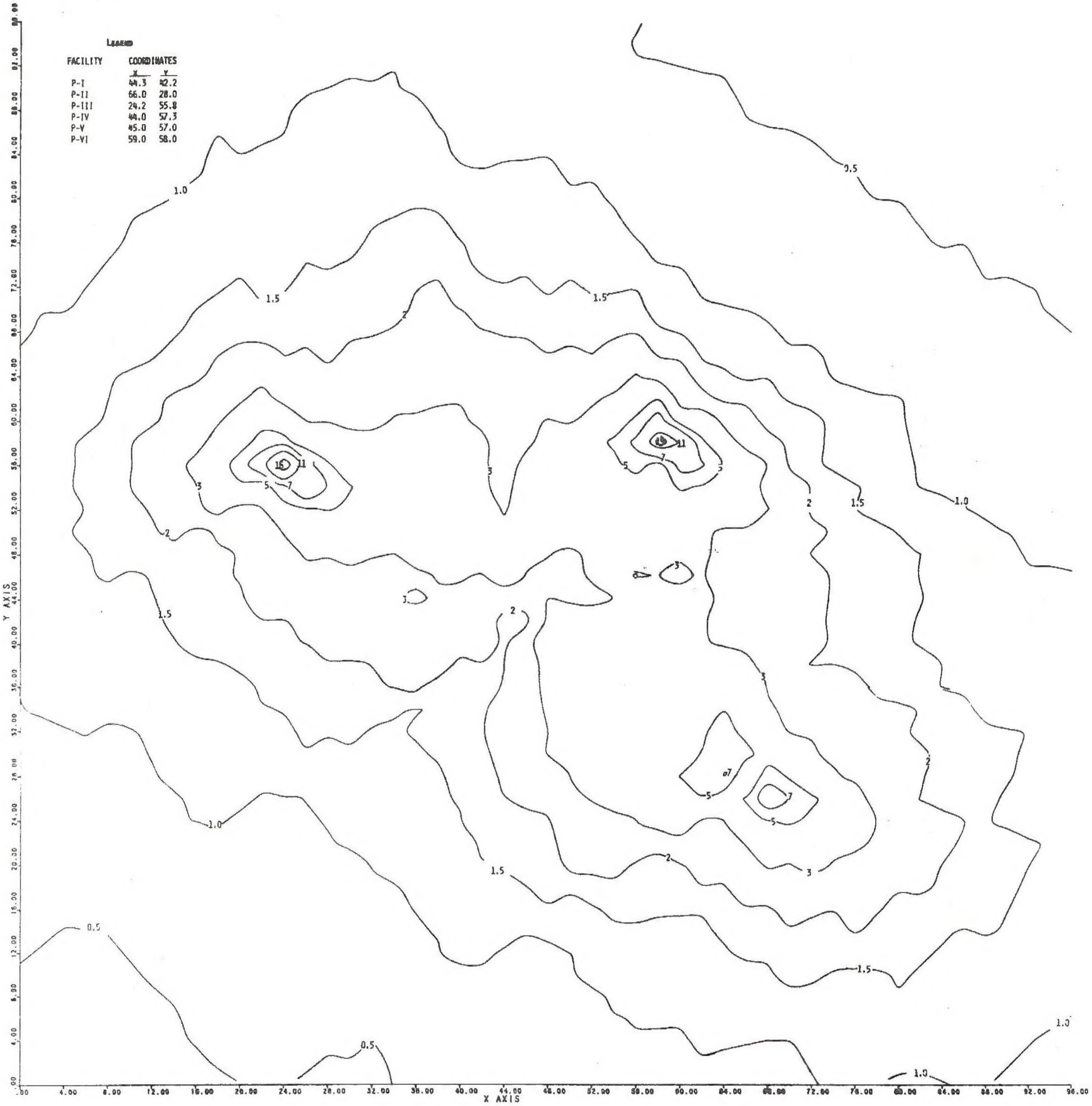


FIGURE 24

COMPOSITE SELENIUM DEPOSITION WITHIN THE STUDY AREA FROM THE SIX COAL-FIRED FACILITIES IN $\mu g/m^2/yr$



LEGEND

FACILITY	COORDINATES X	COORDINATES Y
P-I	44.3	42.2
P-II	66.0	28.0
P-III	24.2	55.8
P-IV	44.0	57.3
P-V	45.0	57.0
P-VI	59.0	58.0

magnitude greater than Facility P-V. Figure 24, when compared to Figure 23, demonstrates the overriding influence of Facility P-VI within a 50 kilometer (km) radius around this facility prior to 1969.

The surface deposition of a trace element has many facets which must be inventoried; for example, some of the trace element falls on leaves of plants and is taken into the plant through leaf surfaces, some is filtered downward through the soil surface, some is relocated by wind and water erosion, and so forth.

A perspective of the magnitude of projected deposition in relationship to the soil concentration of a trace element is demonstrated below. Consider a "worst" case situation from Figure 24 in which the annual deposition occurs directly on the soil surface and remains on the surface in an extractable form. A typical soil density of 1.5 grams per cubic centimeter (gm/cm^3) is equal to 1 gram per 0.67 cubic centimeters (gm/0.67 cm^3). A cube of 0.67 has a surface area of 0.76 square centimeters (cm^2) and a depth of 0.87 centimeters (cm). In Figure 24, the maximum deposition is 19.15 micrograms per square meter per year (μg/m^2/yr), which is equivalent to 0.00146 micrograms per 0.76 square centimeters per year (μg/0.76 cm^2/yr). In this "worst case" situation, the annual soil enrichment per gram of surface soil is therefore 1.46×10^{-3} micrograms.

Table 6 lists the average selenium extractable soil concentration in surface samples as <0.20 micrograms per gram (µg/gm). Considering the surface concentration as 0.20 micrograms per gram (µg/gm), the "worst case" soil enrichment of 1.46×10^{-3} micrograms per gram (µg/gm) is 0.72% of the measured extractable soil concentration at that location. The relatively low annual rate of deposition does not imply insignificant impacts on available soil nutrients to plants, direct leaf uptake, wind and water erosion concentration in localized areas, or to animal and human health. These impacts must be placed into a perspective relative to existing exposure of living organisms to trace elements. The nature of any potential impacts will be addressed during continuing phases of this project.

CONCLUSIONS

This investigation of trace elements was designed and directed toward the achievement of five specific objectives. These objectives are: to identify potential-problem trace elements in coal, to determine the trace element profile of soils, to determine the rate and concentration build-up of trace elements in the soil reservoir from existing coal-fired power plants, to determine by dispersion modeling of air emissions the projected soil reservoir build-up of trace elements, and to examine the need for development of specialized control procedures for the trace element wastes from energy conversion facilities.

The identification of potential problem trace elements in coal ultimately rests with the dispersion and deposition of those elements to the environment through a translocation process involving the energy conversion of coal. In order to identify specific elements which may be producing or eventually produce adverse environmental effects, it is necessary to develop base data on the concentrations of each element in coal, their distribution by type of coal being utilized, and emission concentrations as a result of combustion processes.

The concentrations of fifteen specific trace elements in lignite coal were examined. These fifteen elements found in coal represent many of the trace elements which, when enriched in the environment, present the potential for environmental impacts upon the biological components of a given ecosystem.

The analysis of the data has shown the trace element chemical relationships in coal to vary from mine to mine and within the coal beds of a given mine. On the basis of this information, the identification of potential-problem trace elements in coals must be approached from consideration of multiple coal analysis at a given mine in order to realistically evaluate the fate of these elements within a specific combustion process and the resulting emission concentrations dispersed and deposited over the surrounding environment.

In the course of examining the trace element enrichment of soils by atmospheric deposition, a comparison was made of relative differences in deposition rates between a coal-fired electrical generating facility designed in the 1920's and one designed in the 1960's. Although the more contemporary design used 15 times more coal than the facility designed in the 1920's, the maximum annual deposition rate attributed to the contemporary design was 1/50th of that of the smaller, 1920 facility. In consideration of maximum annual deposition rate per unit of electrical generation, the 1960 facility was found to be one thousandth of the rate for the facility which was designed in the 1920's.

There is a tendency to equate size of facilities with potential problems, the larger the facility the greater the problem.

Historical problems of pollution are not directly transferable without taking into account increased control of emissions, increased operating efficiencies and improvements in other design parameters. Although facility size and the magnitude of coal utilization are important considerations in environmental protection decisions, smaller is not necessarily better. The degree of emission control, dispersion characteristics of the facilities and interactions of multiple facilities are the major factors which must be considered in the decision-making process concerning the siting of energy conversion facilities.

The fate of trace elements within the combustion process of coal-fired electrical generating facilities could not be evaluated since such research was outside of the scope of this investigation. However, research efforts have been performed on the subject of trace element flows and mass balances in the combustion process. This information was evaluated to provide a basis for the assumptions applied to the calculation of emission rates utilized in the projection of ground level trace element deposition in the study area.

A review of the literature (Kaakinen et al., 1975; Cuffe et al., 1964; Capes et al., 1974; Billings et al., 1973; Davidson et al., 1974; and Diehl et al., 1972) concerning trace element mass balance flows and emission rates from electrical generating facilities has served to highlight the factors to be weighed in establishing trace element emission rates. These factors include the specific boiler configuration, operating temperatures, coal chemical composition, emission control device(s), and the lack of reliable analytical standards to be used in the analysis of trace elements in coal, fly ash, and flue gases. From the work of these investigators and others (Lee and von Lehmden 1973; Schulz et al., 1975), the establishment of trace element emission rates and resulting deposition projections must be based on process-specific trace element data within a specific geographical area in order to address the question of environmental significance of any trace element.

The projected deposition of trace elements from six existing lignite coal-fired electrical generating facilities was evaluated in the course of this study. Emission rates utilized in the determination of the deposition were established for each facility using applicable data specific to that facility.

Through the application of an emission rate for the element selenium, an annual soil deposition was obtained. The projection of the depostion was performed using a climatological dispersion model with a deposition function yielding results in micrograms per square meter per year. The deposition units were subsequently converted to micrograms per 0.76 square centimeters per year (surface area of the cubic volume of one gram of soil) for comparison of the annual deposition relative to the existing soil trace element levels. This analysis showed the annual deposition for the element selenium to be a maximum of 0.72% of the measured extractable soil concentration in the study area. This percentage was determined by dividing the maximum annual deposition by the minimum detectable limit concentration for selenium. As previously stated in the discussion, the choice of the element selenium for presentation of this analysis was arbitrary and does not imply that this element is more or less environmentally hazardous than any of the other fourteen elements involved in this investigation.

Lee and von Lehmden, 1973, have established that trace elements such as arsenic, beryllium, cadmium, chromium, nickel, selenium, vanadium, and zinc, are being mobilized in the atmosphere in association with particles emitted from fossil fuel combustion. It has also been shown by these authors and others (Kaakinen et al., 1975; Davidson et al., 1974; and Natusch et al., 1974) that the specific concentration of many trace elements, most notably lead, cadmium, zinc, chromium, vanadium, nickel, and copper, increase with decreasing particle size in fly ash derived from coal combustion. Consequently, the highest trace element concentrations are found in small particles (less than 10 microns in diameter). Only a small fraction of the total fly ash mass has a particle diameter of less than 10 microns. Typical emission control efficiencies for these smaller particles are less than 85%. However, the fraction emitted could present a potential environmental hazard.

The significance of this analysis is that potentially adverse trace elements in coal can be identified through their deposition to the environment, and that a methodology is available for making such determinations. The methods developed and utilized for projection of deposition patterns in this study are transferable and may be applied to any conversion process throughout the region, but variations of coal and soil geochemical data as well as conversion processes dictate a requirement for site specific analysis.

The dispersion-deposition methodology identifies elements in coal which have potential for environmental significance when compared to existing element concentrations. However, in the final analysis, the environmental significance of trace element deposition can only be determined by examining the environmental effect of that deposition over time. The environmental significance of trace elements depends upon the projected soil reservoir deposition of trace element emissions, the rate over time that this deposition occurs, and finally the relationship of the deposition of a trace element to the existing environmental receptor concentrations. The possible environmental effects of exposures from trace elements were identified by an extensive review of the literature. A summary of this review is presented in Appendix C.

The determination of the environmental effect or potential hazard of a trace element when released to the environment must be weighed in light of a number of factual considerations and variables. Many considerations are specific to individual elements while others are applicable to groups of elements. Other considerations are also specific to the particular component of the environment upon which the potential effect is to be assessed. For example, the physical and chemical properties of the element and its subsequent interactions in the effluent streams of energy conversion facilities are directly related to factors affecting the deposition quantities, availability to environmental receptors, and the toxicity to that receptor.

The subsequent movement of an element in the soil depends upon the element's chemical properties. A trace element, when deposited, may be in an insoluble form or complexed with insoluble soil materials and exhibit no mobility or detectable effect. The movement of the element in soluble form into the soil matrix is subject to element-specific factors such as the soil pH, moisture content, and geochemical nature of the existing matrix itself. (See Appendix C1) The movement of an element into the soil matrix becomes interrelated with subsequent uptake by vegetation and soil organisms.

Vegetation may be affected by trace element deposition along several pathways. These are direct deposition of the element on the above ground plant surfaces and absorption through the root systems. However, the concentrations required to cause adverse effects through these pathways vary from element to element, and between species of plants, in addition to the nature of the chemical form of the element. (See Appendix C2)

The movements of trace elements through the environment are intricately interrelated through the soil, vegetation, and animal food chain links. (See Appendix C3 and C4) The complexities of trace element movement through the environment of living organisms are such that they could not be explored in depth within the limited scope of this investigation. Therefore, inference as to the effects of any one trace element or group of elements on the geochemical and biological components of the environment could not be formulated at this stage of study.

The deposition analysis presented for selenium showed the annual rate to be small in relationship to the concentrations found to exist in the soils throughout the study area. Annual depositions for the other fourteen elements under consideration can also be examined by application of the methodology established in this study.

On the basis of adverse response levels found in the literature (Appendix C), the projected depositions on environmental receptors calculated in this phase of research are not expected to cause adverse effects on ecosystems during the short-term period of one year. However, questions still remain relative to the potential long-term effects of trace element emissions in the study area. These questions become of greater significance with a projected increase in coal utilization in the study area and the states of the Old West Region.

APPENDIX A

Trace Element Concentrations In Various Coals

Trace Element Concentrations in Various Coals

Arsenic:	Concentration	Reference
Percent in ash:	0.2%	Duck and Himes (1951)
Lignite percent in ash:	0.1 - 1.0%	Deul and Annell (1956)
Percent in ash:	0.8%	Stewart (1963)
All coals, average:	5.0 ppm	Bertine and Goldberg (1971)
Lignite, Center, ND	5.0 ppm	Ebasco Services, Inc. (1973)
Lignite, Stanton, ND	8.0 ppm	Basin Electric Power Cooperative (1972)
Lignite, Underwood, ND	6.4 ppm	Burns and McDonnell (1973)
Lignite	5.0 ppm	Federal Energy Admin. (1975)
Beryllium:		
Lignite: North Dakota	0.1 - 4.0 ppm	Stadnichenko (1961)
Sub-bituminous: Montana	0.1 - 9.1 ppm	
Sub-bituminous: Wyoming	0.1 - 0.7	
All types: average	3.0 ppm	Bertine & Goldberg (1971)
Lignite: North Dakota	0.23 ppm	North Dakota Geological Survey (1973)
Lignite: North Dakota	0.54 ppm	Burns & McDonnell (1973)
Coals: Central U.S.	0.64	Zubovic (1966)
Lignite coal: range	<0.1 - 8.2 ppm	Zubovic et al. (1961)
Lignite: Center, ND	2.0 ppm	Ebasco Services, Inc. (1973)
Lignite: Stanton, ND	0.58 - 2.6 ppm	Basin Electric (1972)
Lignite: Northern U.S.	0.3 - 30.0 ppm	Sondreal et al. (1968)
Coals: Central & Western U.S.	0.2 - 4 ppm	Ruch et al. (1974)
Lignite: Center, ND	0.60 ppm	Radian Corporation (1975)
Cadmium:		
U.S.: all types	0.2 - 10.0 ppm	Abernethy et al. (1969)
Bituminous coal from:		
Illinois and Kentucky:	1.0 - 2.0 ppm	Lagerwerff et al. (1970)
Lignite: Underwood, ND	0.01 ppm	Burns & McDonnell (1973)
Lignite: Center, ND	0.67 ppm	Ebasco Services, Inc. (1973)
Lignite: Stanton, ND	0.21 - 0.53 ppm	Basin Electric Coop. (1972)
General: Central & Western ND	0.10 - 65.0 ppm	Ruch et al. (1974)
Chromium:		
All Types: Average	10 ppm	Bertine & Goldberg (1971)
Lignite: Stanton, ND	77 ppm	Basin Electric (1972)
Lignite, Western ND	4.0 ppm	North Dakota Geological Survey (1973)
Coal, Central U.S.	12 ppm	Zubovic (1966)
Lignite, ND average:	7.5 ppm	Zubovic (1961)

Copper:	Concentration	Reference
Lignite: Western ND	1.70 ppm	North Dakota Geological Survey (1973)
Sub-bituminous: Montana	11 - 18.0 ppm	Dept. of Health and Env. Science (1976)
Lignite: Center, ND	10.5 ppm	Radian Corporation (1975)
	<1.0 - 45 ppm	Zubovic (1966)
Lignite ash: North Dakota	.001-.03% by wt/ash	Zubovic et al. (1961)
Lignite: Underwood, ND	16 ppm	Burns & McDonnell (1973)
Lignite: Stanton, ND	15 - 34 ppm	Basin Electric (1972)
	15 ppm	Bertine & Goldberg (1971)
All types: U.S.	5 - 61 ppm	Ruch et al. (1974)
	.0001-0.1% wt/ash	Deul & Annell (1956)
Lignite ash: ND	.025% wt/ash	Brewer & Ryerson (1935)
Lignite - sub-bituminous	58 - 3020 ppm	O'Gorman & Walker (1972)
Lead:		
U.S. Coals: average percent in ash:	0.01 - 0.13%	Abernethy & Gibson (1963)
Lignite coal: Center, ND	0.86 ppm	Radian Corporation (1975)
U.S. coals: average	25 ppm	Bertine & Goldberg (1971)
Poplar River coals: Montana range	11 - 27 ppm	Dept. of Health and Env. Science (1976)
Lignite: Western ND	2.70 ppm	North Dakota Geological Survey (1973)
Lignite: Underwood, ND average	0.5 ppm	Burns & McDonnell (1973)
Lignite: Center, ND	7.0 ppm	Ebasco Services (1973)
Lignite: Stanton, ND range	5.4 - 11 ppm	Basin Electric (1972)
Lignite and sub-bituminous: Average: Range:	60 ppm 20 - 165 ppm	O'Gorman & Walker (1972)
Lignite: in percent of ash	0.1 - 1.0%	Deul & Annell (1956)
All samples Central and Western United States	4.0 - 218.0 ppm	Ruch et al. (1974)
Mercury:		
U.S. coals: average range	0.5 - 3.3 ppm	Grant (1971)
U.S. sub-bituminous coal:	1 - 25 ppb	Joensuu (1971)
Central and Western U.S.:	0.02 - 1.60 ppm	Ruch et al. (1974)
Range (percent mercury in ash):	0.007 - 0.019%	Headlee & Hunter (1955)
Western coals (percent mercury in ash)	<0.10%	Deul & Annell (1956)
Lignite: Center, ND	0.074 ppm	Radian Corporation (1975)
Lignite: Center, ND	0.10 ppm	Ebasco Services, Inc. (1973)
Lignite: Stanton, ND	<0.20 ppm	Basin Electric (1972)
Lignite: Underwood, ND	0.094 ppm	Burns & McDonnell (1973)

Molybdenum:	Concentration	Reference
Samples: Central and Western U.S.	1 - 30 ppm	Ruch et al. (1974)
Lignite coal: North Dakota	1 - 100 ppm	Sondreal et al. (1968)
Coal average:	32 ppm	Abernethy (1969)
Coals, average:	1.5 ppm	Magee & Hall (1973)
Lignite: Stanton, ND	5.2 - 17.0 ppm	Basin Electric (1972)
Lignite: Western ND average	3.8 ppm	North Dakota Geological Survey (1973)
Lignite: ND average	0 - 12.8 ppm	Zubovic et al. (1961)
Nickel:		
Average concentration	15 ppm	Bertine and Goldberg (1971)
Range observed in coal ash:	3.0 - 10,000 ppm	Abernethy & Gibson (1963)
Central and Western U.S. coal		Ruch et al. (1974)
average:	21 ppm	
range:	3.0 - 80.0 ppm	
Northern Great Plains lignites	10 - 300 ppm	Sondreal et al. (1968)
Lignite and sub-bituminous coals	20 - 420 ppm	O'Gorman & Walker (1972)
Lignite: ND average	1.90 ppm	North Dakota Geological Survey (1973)
Lignite: ND range	1.3 - 40.0 ppm	Zubovic et al. (1961)
Lignite: Center, ND	13 ppm	Ebasco Services, Inc. (1973)
Lignite: Stanton, ND	7.5 - 60.0 ppm	Basin Electric (1972)
Lignite: Center, ND	5.4 ppm	Radian Corporation (1975)
Selenium:		
U.S. coal samples		Pillay et al. (1969)
Average	3.2 ppm	
Range	0.46 - 10.65 ppm	
Lignite: Center, ND	1.3 ppm	Radian Corporation (1975)
Lignite: Stanton, ND	0.10 - 0.41 ppm	Basin Electric (1972)
Lignite: Center, ND	1.3 ppm	Ebasco Services (1973)
Coals from Central and Western U.S.:	2.08 ppm	Ruch et al. (1974)
Range:	0.45 - 7.70 ppm	
Vanadium:		
Range of vanadium concentrations for U.S. coals:	16 - 176 ppm	Athanasiadis (1969)
Lignite: Stanton, ND	0.23 - 1.7 ppm	Basin Electric (1972)
Lignite: Center, ND	28 ppm	Ebasco Services, Inc. (1973)
Lignite: North Dakota average	11 ppm	North Dakota Geological Survey (1973)
Lignite: North Dakota range	2.2 - 355 ppm	Zubovic et al. (1961)
Lignite and sub-bituminous		O'Gorman & Walker (1972)
Average:	125 ppm	
Range:	20 - 250 ppm	
United States coals average:	94 ppm	Abernethy (1969)
Central and western U.S. coals		Ruch et al. (1974)
Average:	32.71 ppm	
Range:	11 - 78 ppm	

Zinc:	Concentration	Reference
Lignite: Stanton, ND	20 - 79 ppm	Basin Electric (1972)
Lignite: Center, ND	9.8 ppm	Ebasco Services, Inc. (1973)
Lignite: North Dakota average	2.90 ppm	North Dakota Geological Survey (1973)
Lignite: North Dakota range	0 - 1800 ppm	Zubovic et.al. (1961)
Montana, Poplar River Coal Project:	7 - 16 ppm	Dept. of Health and Env. Science (1976)
Lignite and sub-bituminous range:	50 - 320 ppm	O'Gorman & Walker (1972)
Average: all coals	50.0 ppm	Bertine & Goldberg (1971)

Fluoride:		
Lignite: Center, ND	112 ppm	Ebasco Services, Inc. (1973)
Lignite: Stanton, ND	100 - 670 ppm	Basin Electric (1972)
Coal: Central & Western U.S.		Ruch et al. (1974)
Range:	25 - 143 ppm	
Average:	60 ppm	
Coal: Eastern & Central U.S.	85 - 167	Churchill et al. (1948)
Lignite: Center, ND	57 ppm	Radian Corporation (1975)

Sulfur:		
Average sulfur content of U.S. coals:		DeCarlo et al. (1966)
Bituminous coal:	<0.7 - >4.0%	
Sub-bituminous coal:	<0.7 - 2.0%	
Lignite coal:	<0.7 - 1.5%	
Anthrocite:	<0.7 - 2.5%	
Sulfur content of North Dakota lignite by County:		DeCarlo et al. (1966)
Adams:	0.8 - 1.0%	
Bowman:	0.8 - 1.0%	
Burke:	<0.7 - 0.7%	
Burleigh:	<0.7 - 0.7%	
Dunn:	<0.7 - 0.7%	
Grant:	0.8 - 1.0%	
Hettinger:	<0.7 - 0.7%	
McLean:	<0.7 - 0.7%	
Mercer:	0.8 - 1.0%	
Morton:	1.1 - 1.5%	
Oliver:	0.8 - 1.0%	
Stark:	<0.7 - 0.7%	
Ward:	<0.7 - 0.7%	
Williams:	<0.7 - 0.7%	

Total sulfur in North Dakota lignite by County and Mine: — Walker & Harner (1966)

County	Mine	
Adams	Arrowhead	1.07%
Bowman	Twin Buttes	0.90%
Burke	Bonsness	0.32%
	Kincaid	0.46%
Burleigh	Burleigh	0.64%
Mercer	Indianhead	0.57%
	Kamins	0.57%
	Knife River	0.88%
Morton	Flemmer	0.61%
Ward	(All mines)	0.25%
Williams	Avoca	0.62%
	Ray	0.43%
	Standard	0.60%
	Williston View	0.45%

Total sulfur content of lignite shows an average range of:	0.1 - 1.9%	Sondreal, E.A. et al. (1968)
Total sulfur content: Poplar River Project - Montana average:	0.9%	Dept. of Health and Env. Science (1976)
Total content of U.S. coals by State: (average)		Rohrman & Ludwig (1965)
Montana:	0.70%	
North Dakota:	0.81%	
South Dakota:	0.70%	
Wyoming:	0.61%	

APPENDIX B

Trace Element Concentrations In Soils

Trace Element Concentrations in Soils

Arsenic:	Concentration	Reference
Normal virgin soils:	1.3 - 2.5 ppm	Headden (1910)
Orchard soils, Western U.S.:	5.0 - 102.0 ppm	Greaves (1913)
Orchard soils, Oregon	3.0 - 14.0 ppm	Jones and Hatch (1937)
Normal surface soils: U.S.:	0.4 - 41.0 ppm	Williams and Whetstone (1940)
Natural conc. range of arsenic in soils:	5.0 ppm	Hawkes and Webb (1962)
Normal conc. range in soils:	1.0 - 70.0 ppm	Stewart (1963)
Concentration range in soils:	0.3 - 40.0 ppm	Misra and Tiwari (1963)
Average arsenic conc. in soils:	6.0 ppm	Miesch and Huffman (1972)
Normal soils; United States:	1.0 - 97.0 ppm	Shacklette et al. (1974)
Total arsenic conc. range: all soils	0.0 - 500.0 ppm	Federal Energy Admin. (1975)
Beryllium:		
Earth's crust: average	6.0 ppm	Goldschmidt (1954)
Soils: average range	6.0 ppm 0.1 - 40 ppm	Bowen (1966)
Scottish soils:	<5.0 ppm	Swain and Mitchell (1960)
Cadmium:		
Average conc.: Earth's crust	0.15 - 0.20 ppm	Fleischer et al. (1974)
Uncontaminated soils: U.S.	<1.0 ppm	Shacklette et al. (1973)
	0.5 - 2.0 ppm	Miesch & Huffman (1972)
Uncontaminated soils: U.S.	0.01 - 0.7 ppm	Fulkerson et al. (1973)
Avg. conc.: Normal soils	0.06 ppm	Bowen (1966)
Non-polluted soils	0.01 - 7.0 ppm	Allaway (1968)
Non-polluted - background	0.5 ppm	Warren et al. (1971)
Field soil, unfertilized fertilized	0.55 - 2.45 ppm 3.38 ppm	Schroeder (1967)
Chromium:		
Soil: Average	5.0 - 1000 ppm	Swaine (1955)
Soils: U.S. average	1.0 - 250 ppm	Robinson (1914)
Soils: Average	100 ppm	Bowen (1966)
Topsoil: NJ & PA	12 - 51 ppm	Conner et.al. (1957)
Copper:		
United States	10 - 40 ppm	Bear (1957)
	20 (average) ppm	Hodgson (1963)
	2 - 100 ppm	Allaway (1968)
United States average:	2.5 - 125 ppm	Shacklette (1970)
North Dakota Samples	<12 - >37 ppm	Shacklette (1970)

	Concentration	Reference
Atlantic Coastal Plain	5 - 27 ppm	Holmes (1943)
Central and Western U.S.	6 - 67 ppm	Holmes (1943)
Native Soil (U.S.)	10 - 200 ppm	Reuther & Labanauskas (1966)
Atlantic Coastal Region	1 - 30 ppm	
	7 - 30 ppm	Pratt & Bradford (1958)
Michigan Soils	14 - 120 ppm	Lucas (1948)
Utah Soils	7.2 - 24.5 ppm	Greaves & Andersen (1936)
Lead:		
Normal uncontaminated soils	0.05 - 5.0 ppm	Brewer (1966)
Natural concentration range	2.0 - 200 ppm	N.R.C. (1972)
World-wide average:	16 ppm	Goldschmidt (1937)
Average concentration:	10.0 ppm	Bowen (1966)
Normal concentration range:	6 - 108 ppm	Wright (1955)
Mercury:		
Mercury concentrations found in various soil categories:		Klein (1972)
Residential soils:	0.07 - 1.10 ppm	
Agricultural soils:	0.09 - 0.11 ppm	
Industrial soils:	0.10 - 0.14 ppm	
Average concentration: all soils and rock	0.05 ppm	Grant (1971)
Soil concentration average: U.S.		Shacklette (1971)
Eastern U.S.:	96 ppb	
Western U.S.:	55 ppb	
Natural background concentration in Western U.S.:	100 ppb	Pierce et al. (1970)
Natural concentration range of mercury in soils:	30 - 300 ppb	Hawkes & Webb (1962)
Average concentration: rocks and soils	100 ppb	Hammond (1971)
Average concentration of mercury in the Earth's crust:	0.07 ppm	Vinogradov (1959)
Average abundance of mercury: Earth's crust	0.5 ppm	Goldschmidt (1954)
Average: natural soils	0.10 ppm	Wallace et al. (1971)
Molybdenum:		
Natural background concentration:	0 - 0.5 ppm	Barshad (1948)
Average molybdenum content of soils:	2.5 ppm	Robinson & Alexander (1953)
Average molybdenum content: U.S. soils	0.6 - 3.5 ppm	Robinson et al. (1951)
Average molybdenum content (181 random samples):	1.33 ppm	Clark & Axley (1955)
Range:	0.13 - 13.54 ppm	
Normal random soil samples:	0.79 - 2.21 ppm	Purvis & Peterson (1956)
Samples of New Jersey soils:	0.80 - 3.3 ppm	Evans & Purvis (1951)
Normal soils: Scotland	0 - 2 ppm	Mitchell (1944)

	Concentration	Reference
Total molybdenum content of soils: range	1.0 - 3.0 ppm	Bear (1957)
Average concentration molybdenum in Earth's crust:	2.3 ppm	Goldschmidt (1954)
Normal background soil concentration:	0.1 - 5 ppm	Mitchell (1964)
Normal background soil concentration:	2.0 ppm	Bowen (1966)
Average concentration in U.S. soils:	3 ppm	Shacklette (1970)
Soil concentration: Canadian Atlantic coastal area	0.05 - 12.1 ppm	MacLean & Langille (1973)
Total molybdenum in soils:	0.2 - 5 ppm	Bould (1963)
Nickel:		
Normal concentration of nickel:		Swaine (1955)
Average:	100 ppm	
Normal range:	5 - 500 ppm	
Normal concentration of nickel: Eastern U.S.	2.5 - 40 ppm	Painter et al. (1953)
Normal background concentration: Southern California	8 - 100 ppm	Vanselow (1952)
Normal range of nickel: soils	>1 - 100 ppm	Rogers et al. (1939)
Average concentration: Earth's crust	80 ppm	Sandell (1943)
Total nickel in soils: range	10 - 40 ppm	Bear (1957)
Average concentration of nickel: Earth's crust	100 ppm	Goldschmidt (1954)
Normal concentration of nickel in soil:	40 ppm	Bowen (1966)
Selenium:		
Earth's crust, normal range	0.03 - 0.8 ppm	Fleischer (1953)
Earth's crust, average concentration:	0.09 ppm	Goldschmidt (1954)
Volcanic rocks, Western U.S.	2.0 ppm	Davidson & Powers (1959)
Normal concentration of soils:	0.1 - 2.0 ppm	Swaine (1955)
Limestone materials: SD	<3.0 ppm	Moxon et al. (1938)
Sedimentary rocks: SD	0.2 - 33.5 ppm	Lakin (1961)
Sedimentary rocks: Western U.S.	0.02 - 1,500 ppm	
Soils: Gregory County, SD	0.5 - 13 ppm	Byers (1935)
average:	4.5 ppm	
Seleniferous soils: Western U.S.	1 - 6 ppm	Byers et al. (1938)
Soil concentration range entire U.S.	0.1 - 4.32 ppm	Shacklette et al. (1974)
Vanadium:		
Normal soils range:	3 - 230 ppm	Pratt (1966)
Normal soil range:	20 - 500 ppm	Swaine (1955)

Zinc:	Concentration	Reference
Zinc concentration in the lithosphere	80 ppm	Goldschmidt (1954)
Range of zinc in normal soils:	10 - 300 ppm	Swaine (1955)
Range of zinc in normal soils:	20 - 200 ppm	Bear (1947)
Average concentration of zinc in normal soils:	58 ppm	Vinogradov (1959)
Average concentration of zinc in normal soils:	50 ppm	Bowen (1966)
Normal zinc concentration for soil profiles in various areas:		Holmes (1943)
Atlantic Coastal Plain:	13 - 31 ppm	
Wisconsin Soils Profiles:	61 - 79 ppm	
Iowa Soil Profiles:	48 - 72 ppm	
Kansas Soil Profiles:	58 - 81 ppm	
Mississippi Drainage Basin:	34 - 120 ppm	
Fluoride:		
Average concentration: Pennsylvania soils	240 ppm	Steinkoenig (1919)
Average concentration: Surface soils, U.S.	292 ppm	Robinson & Edington (1946)
Average concentration: Entire U.S.	180 ppm	Shacklette et.al. (1974)
Average: Western U.S.	250 ppm	
Average: Eastern U.S.	115 ppm	
All soils, average concentration:	100 - 300 ppm	Bear (1957)
All soils, average concentration:	200 ppm	Bowen (1966)
Average concentration: all soils	300 ppm	Goldschmidt (1954)
Range of concentration:	10 - 1000 ppm	Bould (1963)
Sulfur:		
Total sulfur, field soils - average:	0.01 - 0.05%	Starkey (1950)
Total sulfur, American soils - average:	0.01 - 0.06%	Greaves & Gardner (1929)
Total sulfur, topsoil - range:	0.008-0.136%	Jordan & Ensminger (1958)
average total sulfur:	0.045%	
Soil sulfate, average concentration:	0.01 - 0.02%	Barbier & Chabannes (1944)

APPENDIX C

The Effects of Selected Trace Elements On:

Soils . . . . Appendix C1

Vegetation. . . . . Appendix C2

Animal Nutrition and Health . . . . . Appendix C3

Human Nutrition and Health . . . . . Appendix C4

The Effects of Selected Trace Elements on Soils

Arsenic:	Concentration	Reference
Arsenic residues contaminating soils are usually quite stable and are dispersed by leaching.		Johnson and Hiltbold (1969)
Arsenates are relatively insoluble in soils, not lost by leaching and accumulate.		Bear (1957)
Chemistry of As in soils is similar to that of phosphorus. Absorption is related to free iron oxide with increasing absorption as free iron oxide content increases.		Jacobs et al. (1970)
Arsenic contamination of soil shows low penetration with increasing soil depth.		Williams and Whetstone (1940)
Arsenic and phosphorus show similar soil chemistry and attempts to reduce arsenic solubility coincidently can decrease levels in available soil phosphorus.		Underwood (1962)
Cadmium:		
Cadmium becomes associated with soil organic matter and may be geochemically recycled similar to mercury.		Fleischer et al. (1974)
Cadmium appears to be mobile in the industrially contaminated soils and was found at higher than expected background concentrations at depths to 30 centimeters.		Kobayashi (1971)
Cadmium content of soil markedly affects the cadmium content of plant roots. The type of soil appears to affect the movement of cadmium into plant roots and shoots.		John et al. (1972)
Chromium:		
Chromium has been associated with infertility in the soil at concentrations of:	1000 - 3900 ppm	Robinson et al. (1935)
The application of phosphate to the soil has shown the effect of intensification to chromium toxicity symptoms in various plants.		Hunter & Vergnano (1953)
Chromium additions to soil appears to cause only slight reductions of plant yield at levels of:	2 ppm	DeKock (1956)
Soluble chromium added to soils is likely to revert to insoluble oxides and results in only a temporary increase in extractable soil chromium concentrations.		Sullivan (1969)
Copper:		
Additions of copper to the surface of peat soils may remain in the top two inches for at least six years.		Mitchell (1964)
Copper often accumulates in topsoil, strongly absorbed to silicate mineral surfaces or chelated by organic matter. Soil treatments and climatic conditions which tend		Lagerwerff (1967)

	Concentration	Reference
to increase soil acidity can cause copper toxicity to occur in vegetation where previously no toxicity problem existed.		
Copper has a pH dependent interaction with soil and becomes very strongly bound and very difficult to leach out or extract.		Hodgson (1963)
Copper has a low mobility in soil and does not readily move through the soil profile.		
Copper applied to organic soils in the form of the cupric ion remains in the zone of placement. Copper is retained by the soil and provides long-term residual effects.		Lucas (1948)
Lead:		
Lead from industrial contamination or from decayed plant material appears to be immobilized in the topsoil. Lead becomes fixed with various anions in the soil surface. Soil profiles demonstrate the apparent lead accumulations in soil surfaces.		Rains (1971)
Lead applied to soil appears to become associated with surface plant roots. Applied soil lead does not appear to affect the absorption of Zn, Cu, Mn, Fe or phosphorus from the soil to plants.		Broyer et al. (1972)
The large additions of soluble lead salts to various soils appears to produce only small increases in the concentration of lead in the tops of plants.		Allaway (1968)
Very close correlations exist between the fertility of the soil and its microflora. The addition of 250 ppm lead in soil with a pH below 4.5 will cause considerable harm to microflora.		Schonbeck (1974)
Lead has been observed to be distributed throughout soil samples with surface soils being somewhat richer in lead than subsoils. Lead content in soil appears to decrease with increasing pH.		Filipovic (1961)
In an instance of airborne contamination of soil by lead, approximately 90% of the metal deposited was retained in the upper 15 cm of soil.		Buchauer (1973)
Under acid soil conditions, the amounts of lead taken up by plants appears to be reduced with the addition of phosphate or lime.		MacLean et al. (1969)
Mercury:		
When soil has been contaminated with mercury compounds, the application of lime-sulfur or of elemental sulfur has decreased the mercury availability to vegetation.		Lagerwerff (1967)

	Concentration	Reference
Mercury, when deposited on the soil, is retained in the upper soil surface on aerated soils. Mercury is retained through a valence-type ionic absorption by organic and inorganic materials. Also, retention takes place because many of the mercury compounds in soil have low solubilities such as mercury as phosphate, carbonate, and sulfide complexes.		Lagerwerff (1972)
In anaerobic soil conditions, mercury is at least partially converted into soluble forms such as monomethyl or gaseous dimethyl mercury complexes.		
Molybdenum:		
The molybdenum status of soil and its pH appear to be the main determinants of the level in all plant species. Molybdenum is not readily absorbed from acid soils and liming of such soils will increase molybdenum uptake by plants. High molybdenum concentrations in plants is usually associated with alkaline soils.		Underwood (1962)
The molybdenum found in alkaline soils appears to be highly water soluble and by acidification of the soil, the water soluble molybdenum concentration can be greatly reduced.		Barshad (1948)
Molybdenum accumulation by forage plants appears to be affected by its concentration in neutral soil, by species of plant, and by the depth of the water table. Accumulation of molybdenum by plants is proportional to the amount of soluble molybdenum added to soil in a pH range of 4.7 - 7.5. Forage grown where the water table is near the soil surface contained more molybdenum than did vegetation where the depth of the water table is greater. In the study, the growth of alfalfa was retarded when soil concentration of water soluble molybdenum reached levels of:	1500 ppm	Jensen & Lesperance (1971)
Molybdenum added in soluble form to most soils is quickly precipitated and slowly converted to less soluble forms. Leaching is not likely to remove significant amounts of molybdenum through acidic soil profiles except possibly in very sandy soils.		Smith & Leeper (1969)
In acid soils, the application of molybdenum and the natural soil content of molybdenum does not appear to significantly affect the yield of soybeans, but in areas of alkaline soils, the application of molybdenum appears to increase plant concentrations and may reduce the crop yield.		de Mooy (1970)

	Concentration	Reference
The uptake of molybdenum from soil by wheat appears to increase with the addition of nitrogen fertilizers. It appears that the increase uptake may be due to the nitrogen-producing nitric acid which brings more molybdenum into solution.		Mishra et al. (1970)
Excessive molybdenum levels from various areas of the world which appear in herbage appear to be associated with alkaline soils with unusually high amounts of total molybdenum. Under acid conditions relatively high concentrations of molybdenum may be present without uptake by plants of levels significant to produce toxicity in both vegetation and animals.		Davies (1956)
The sorption of molybdate by soils depends on pH and molybdenum concentration. The precipitation of the molybdate ion with the ferric ion shows that ferric molybdate has a very low solubility at acid pH. Molybdenum appears to be more readily absorbed by hydrous ferric oxide than by other soil colloids. The principle that lime makes more molybdenum available to plants is that the molybdenum ion is absorbed by soil ferric hydroxide and becomes quite exchangeable with hydroxyl ions.		Jones (1957)
Evidence indicates that soil reaction is the major controlling factor in the availability of molybdenum to plants. As the pH drops below 7, molybdenum appears to become less available and as the pH rises above 7, molybdenum becomes more soluble and thus more available.		Evans et al. (1951)
On reduction of soil acidity from pH 5 to pH 7, molybdenum uptake by plants is significantly increased. Uptake of molybdenum by plants in amounts toxic to animals normally takes place on alkaline soils or soils with high organic matter contents. Uptake of molybdenum from acid soils of a pH of 5 can also occur if the soil organic matter content is high.		Mitchell (1964)
On most soils tested, ammonium sulfate appears to decrease molybdenum contents of herbage from potentially toxic to animals to marginal or normal concentrations.		Williams & Thornton (1972)
In considering molybdenum in general and its movement in soils, a very high proportion of the element appears to be leached throughout soil profiles.		Jones & Belling (1967)
Molybdenum appears to be readily absorbed by soil. The first absorption within the soil may be through covalent bonding of soil surface hydroxyls or an exchange of surface hydroxyls.		Ellis & Knezek (1972)

	Concentration	Reference
Under normal soil conditions up to approximately 90% of the molybdenum in the soil may occur in a form unavailable to plants.		Bould (1963)
Nickel:		
Nickel appears to be absorbed in the ionic form from the soil or culture solution. Nickel appears to be more easily absorbed by plants when applied in the ionic form. It has been observed to be taken up by plants at a rate of approximately ten times that of complexed nickel.		Crooke (1954)
No positive relationship exists between the nickel content of soil and that of plants unless the pH of the soil is considered. Soil values below pH 5.6 favor absorption of nickel while values of above 5.6 do not. Application of lime to acid soils appear to reduce the absorption of nickel by plants by raising the soil pH.		Vergnano (1953)
Nickel has been found as a soil contaminant in the area of smelting operations. Highest concentrations occur in the immediate area of the smelter and decrease quite rapidly with distance. The nickel appeared to be concentrated in the soil surface layer without movement through the soil profile.		Hutchinson & Whitby (1974)
In general, nickel in soil appears to have increased mobilization in profiles of poorly drained soils.		Swaine & Mitchell (1960)
Selenium:		
It appears that even in soil of low selenium content, drainage waters become enriched with selenium and that selenium is mobilized in the soil by irrigation.		Williams & Byers (1935)
Studies of toxic and non-toxic seleniferous soils has shown climate and the soil development process to be major factors in the availability to plants of the selenium in soils. The toxic soils in the U.S. are pedocal soils, which are alkaline in reaction, contain free calcium carbonate, and lie in regions of low rainfall, usually less than 20 inches mean annual precipitation. No acid soils are known to produce toxic vegetation. In acid soils, the selenium is probably in the form of insoluble ferric selenite. Selenium occurring in soils as selenate appears to be normally leached out. A partial measure of selenium's availability to plants is its solubility in water.		Lakin (1961)
It has been concluded that drastic leaching of soil with the addition of sulfur or gypsum appears to offer an effective method of reducing the danger of selenium in food crops grown on soils previously treated with sodium selenate.		Fuller (1946)

	Concentration	Reference
In considering the water soluble selenium values of soil profiles from South Dakota, it appears that selenium concentrations increase with depth of the sample.		Moxon (1958)
A comparison of the selenium content of crops with amounts of water soluble selenium and organic selenium in soils show a relatively close relationship whereas a comparison of selenium content of crops with total selenium or acid soluble selenium shows practically no direct correlation.		Olson & Moxon (1939)
Under alkaline well-aerated soil conditions, the selenium in soil appears to become oxidized to selenates. Selenates are not strongly absorbed or fixed in alkaline soils and are generally quite available to plants.		Allaway (1968)
Zinc:		
Toxicity in plants has been observed with soil concentrations of approximately:	400 ppm	Barnette (1936)
It has been observed that less zinc is taken up by plants after lime has been applied to acid soil. This effect as the soil pH increases is generally attributed to the formation of insoluble zinc hydroxide. It is commonly thought that zinc availability in soil is at a minimum when the pH ranges from 5.5 - 7.0.		Seatz & Jurinak (1957)
Laboratory studies with soil columns showed practically no downward movement of zinc as a result of leaching. Tests show an appreciable amount of soil applied zinc may remain in the extractable form for several years. It appears that soil applied zinc is immobilized in the soil surface and remains where it is placed.		Brown et al. (1961)
The downward movement of zinc applied to the soil surface appears to be dependent on the type of soil. Zinc moved through the soil profile of sandy soils quite readily but in most other types of soils, little or no mobility was observed.		Barrows et al. (1960)
Long continued accumulation and decay of organic matter under trees and other heavy vegetation causes accumulations of considerable amounts of zinc which becomes easily fixed in the soil surface.		Hibbard (1940)
Zinc appears to exhibit very little mobility within soil profiles and remains relatively fixed in the soil surfaces.		Hodgson (1963)
The solubility of oxides and other naturally occurring compounds of zinc is extremely low and the absorption and binding of the element by soil colloidal particles is sufficiently strong to make it an important process in controlling the availability of zinc to plants.		Ellis & Knezek (1972)

	Concentration	Reference
Zinc deficiencies in crops is not common on acid soils. In soils, zinc content is often higher in the topsoil and this quite possibly could be caused by plant residue deposition or by industrial emissions into the atmosphere with subsequent deposition on the soil surface.		Lucas & Knezek (1972)
Zinc deficiency is most likely to be found in plants growing on soils with calcareous surface horizons or on leach, acid, sandy soils. Zinc deficiency may also occur where the soil is high in phosphorus, due to interactions involving zinc, phosphorus and iron leading to poor utilization of zinc by plants.		Kubota & Allaway (1972)
Fluoride:		
There seems to be no evidence that fluorides from the air build up in soils in sufficient quantities to adversely affect crops. Experimental plants without increased fluoride concentrations have been grown in soil from areas exposed for several years to airborne fluorides.		McClure (1969)
In order for soil fluoride concentrations to be reflected in increased fluoride levels of vegetation, a considerable portion of the total fluoride must be in soluble forms. Fluorides deposited on soil from various sources is converted to insoluble calcium fluoride and thus does not show noticeable effects on the fluoride concentrations of vegetation.		Jewell (1969)
Soluble fluorides in soil become toxic to vegetation at concentrations of approximately:	50 ppm	Bear (1957)
Injury to plants from soil fluorides taken up by the roots is very rare. However, under certain conditions, plants growing on acid soils will accumulate fluorides and exhibit injury symptoms identical to those caused by hydrogen fluoride fumes.		Allaway (1968)
Substantial amounts of the total soil fluorides are in insoluble forms and are not taken up by vegetation.		
The amount of fluorine accumulated from the soil by plants is usually not closely related to the fluoride content of the soil. Soil type, calcium and phosphorus, and soil pH appear to be the predominant controlling factors other than plant species. Toxic range for most plants of soluble fluoride is:	100 - 200 ppm	Brewer (1966)

	Concentration	Reference
Fluorine added to the soil in the form of superphosphates appears to be retained by heavier textured soils. Sandy soils retain less added fluorides. The added fluorides do not appear to increase the fluoride contents of plants to a significant degree.		Robinson & Edington (1946)
Sulfur:		
Soils have been shown to absorb sulfur dioxide directly from the atmosphere. The rate of absorption is dependent upon moisture in the air streams or soils. Sorption increases markedly in the presence of moisture.		Yee et al. (1975)
Direct soil absorption of sulfates decreases as the pH of the soil increases. The amount of sulfate absorbed is directly related to the concentration of sulfates in the exposure media, and increasing soil phosphate concentrations appear to reduce the amount of sulfate absorbed by soil.		Kamprath et al. (1956)
It has been observed that as the pH of the soil is changed from acid to neutral, there is a marked decrease in the amount of sulfate absorbed.		Mattson (1927)
In field studies, when large amounts of phosphate has been added to soil, very little sulfate is found in surface layers indicating that phosphate can replace most surface soil sulfate.		Ensminger (1954)
In studies involving sulfur dioxide and a smelting process, it has been observed that sulfur dioxide fumigation of soil near the smelter appeared to lower the pH of the surface soil layer (acidify) with the soil pH approaching normal with increasing distance from the smelter.		Whitby (1939)

The Effects of Selected Trace Elements on Vegetation

	Concentration	Reference
Arsenic:		
Arsenic accumulation in plant root systems. Not essential for plant growth. Toxic to plants in seedling stage. Symptoms of toxicity: wilting leaves, retardation root and top development.		Liebig (1966)
Severely limits early growth stages of plants.		Williams and Whetstone (1940)
Toxicity of arsenic to plants depends on its solubility in water.		Shacklette et al. (1974)
Toxicity of water soluble arsenic to alfalfa and barley occurs at:	2.0 ppm	Vandecaveye et al. (1936)
Toxicity of arsenic to vegetation is a function of solubility and complex.		Woolson et al. (1971)
Symptoms of As toxicity to plants: slow stunted growth, late maturity, yellowing of leaves, appearance of moisture deficiency. Injury to alfalfa has occurred at:	2.0 ppm	Bear (1957)
Arsenic in soils causes retardation of plant growth at:	4.0 - 12.0 ppm	Federal Energy Admin. (1975)
Toxicity of As compounds to plants:		
Arsenites	10.0 ppm	
Arsenates	5.0 ppm	
Beryllium:		
Beryllium, as it presently occurs, does not represent a factor in the health of crops.		Tepper (1972)
Beryllium has been shown to exert a toxic effect on vegetation which exhibit a magnesium deficiency. The effects appear to come not so much from the beryllium concentrations, but from the deficient concentration of magnesium.		Hoagland (1952)
Cadmium:		
Cd appears to be absorbed by above ground plant parts. Many plants in high Cd polluted areas tend to build surface deposits of the element. Cd content of plants appears to increase with increasing soil concentrations.		Goodman & Roberts (1971)
There are no reports of Cd toxicity occurring naturally under field conditions in plants. Toxicity occurs primarily from industrial contamination.		Fleischer et al. (1974)
Vegetation grown on contaminated soil will accumulate soluble Cd which may cause a potential Cd toxicity hazard to humans.		Page et al. (1972)
Airborne Cd appears to accumulate in plants through a non-metabolic binding of the element on tissue cell walls.		Cutler and Rains (1974)
Concentrations of Cd that are toxic to plants are largely unknown. High levels of Zn usually accompany high levels of Cd in the environment and both may exert a toxic effect.		Shacklette (1972)

	Concentration	Reference
Cd when added in concentrations in excess of that normally found in plants has been seen to stimulate stomatal closure. The photosynthetic process has also been inhibited.		Bazzaz (1974)
Cd toxicity has been seen to occur in soybeans at:	2.5 ppm	Haghiri (1973)
The primary visual toxicity symptom for wheat plants appears to be stunted growth. Cd excess may produce or aggrevate iron deficiency in plants since symptoms resemble iron chlorosis. Aerial contamination of plants by cadmium appears to present the greatest danger to man and animals in terms of potential toxicity.		
Chromium:		
A concentration of chromium as the chromic ion or chromate ion at:	8 - 16 ppm	Hewitt (1953)
produced iron chlorosis in sugar beets in sand cultures. The chromate ion appears to be more toxic than the chromic ion to vegetation.		
Iron chlorosis in oat plants has developed at chromium concentrations of:	5 - 10 ppm	Hunter & Vergnano (1953)
Specific symptoms of chromium toxicity in oats begins to appear at:	15 - 50 ppm	
Toxicity symptoms in oat plants are stunted growth with narrow brownish-red leaves and poorly developed roots. The principal accumulation and toxic effect of chromium appears to occur in the root system.		
Toxicity to tobacco plants has occurred at chromium levels of:	5 ppm	Soane & Saunder (1959)
Toxicity symptoms in corn plants has occurred at chromium levels of:	10 ppm	
Toxicity symptoms observed in corn: Plants become severely stunted, with the leaves showing a tendency to roll and turn greenish-purple in color.		
Chromium has not been noted to have caused damage to plants of importance in agriculture under field conditions.		Smith (1972)
Detrimental effect of vegetation from chromium may occur at concentrations of:	10 - 100 ppm	Allaway (1968)
Chromium is not considered as essential to plants on the basis of present evidence, even though some growth stimulatory effects have been observed. When naturally occurring chromium toxicity to plants has been suspected, it is not certain that chromium is the only potentially toxic element involved.		
The concentration of chromium in oat plants which appears to cause marginal toxicity to the plants is:	124 ppm	Anderson et al. (1975)

Copper:	Concentration	Reference
Symptoms of copper toxicity appear in citrus seedlings in concentrations of:	<50 ppm	Lagerwerff (1967)
Clover and alfalfa are particularly sensitive to excessive copper, showing stunted growth, and dieback.		
Copper toxicity in vegetation has been observed at concentrations of:	20 ppm	Allaway (1968)
In a wide variety of plants, Cu deficiency is characterized by levels of less than:	4 ppm	
Range of copper concentrations required for normal growth:	5 - 20 ppm	
The availability of copper to plants is dependent upon soil pH, but does not normally increase until pH falls below five. High levels of nitrogen and phosphorus can encourage deficiency of Cu in vegetation. Excessive amounts of zinc can actuate Cu deficiency also.		Lucas & Knezek (1972)
Severe copper deficiencies have been induced in citrus by applying phosphorus at a concentration of:	180 ppm	Olsen (1972)
Toxic effects of copper have been decreased by additions of iron but effects have not totally been overcome with iron applications. The application of excessive zinc has been shown to induce copper deficiency in wheat and barley.		
Various species of plants show different symptoms of Cu toxicity, but in general early stages show reduced growth, reduced yield. Moderate to acute toxic stages show terminal growth with dieback of growing points a common symptom. Other symptoms such as chlorosis and necrotic spotting may occur. Many plants show thickening and abnormally dark coloration of rootlets.		Reuther & Labanauskas (1966)
Symptoms of copper deficiency in oat plants have appeared under field conditions at levels of:	2.0 ppm	Teakle et al. (1941)
Copper deficiency in plants symptoms: reduced growth, color change to gray-green or blue-green, dieback of leaves. Wheat, barley and oats are very sensitive to copper deficiency.		Nelson et al. (1956)
Copper deficiency may be indicated in alfalfa at concentrations of:	<1 - 2 ppm	Dye (1962)
No natural occurring toxicity to alfalfa has been recognized.		
In cereals and grasses, Cu concentration increases linearly with increasing nitrogen contents, with a tendency toward higher Cu-N ratios as concentrations of both elements increase. The effects of copper contamination to soil with relation to vegetation are extremely dependent on soil type and pH.		Gladstone et al. (1975)
Copper and nickel exhibit a relationship in instances of Ni toxicity to vegetation. Increasing		Mizreno (1968)

	Concentration	Reference
the Cu-Ni ratio in plants has reduced the degree of nickel toxicity symptoms in plants.		
Copper concentrations in the upper portions of plants tends to decrease with increasing maturity.		Fleming (1965)
Zinc deficiency in plants appears to be aggrevated by increasing copper concentrations in plant roots and tops.		Chaudhry & Lonerogan (1970)
Copper toxicity was induced in plants at a level of:	20 ppm	Hunter & Vergnano (1953)
Specific symptoms begin to appear between:	10 - 20 ppm	
Lead:		
Lead content of rye grass appears to increase with increasing rates of lead addition to the soil. Lead appears to be primarily associated with the root structure and it is concluded that roots of actively growing rye grass provide a barrier which restricts the movement of excessive amounts of lead to above-ground plant parts.		Jones et al. (1973)
Roots appear to accumulate a surface lead precipitate from the soil and slowly accumulate lead crystals in cell walls. This lead is taken up and distributed throughout the above-ground plant parts.		Malone et al. (1974)
Excessive concentrations of lead, when applied to soil, show the effect of decreasing net photosynthesis and transpiration to both soybeans and corn. Corn tends to be a lead accumulator plant. Airborne lead appears to cause a possible interference with gas exchange in the plants.		Bazzaz (1974)
Lead content of the tops of plants appears to correlate poorly with the soil lead concentrations. Root concentrations appear to correlate quite well. Under conditions of adequate sulfur supply, rye grass appears to restrict the movement of lead to upper plant parts. Under conditions of sulfur deficiency, lead in plant tops appears to increase significantly.		Jones et al. (1973)
The effects of lead on plant growth appear to be accentuated under conditions of phosphate deficiency.		Koeppe & Miller (1970)
Various vegetables and cereal crops do not appear to be significantly affected by the concentration of lead in the air. The inedible portions of the plants do appear to absorb lead from the air but the soil appears to be the primary source of lead in edible plant portions.		Ter Haar (1970)
Lead originating from contamination or from decayed plant tissue tends to be retained in the soil surface. Surface rooting plants appear to be		Lagerwerff (1967)

	Concentration	Reference
more significantly affected by soil lead deposition than deep rooting plants. The liming of soil appears to diminish the toxicity of high concentrations of soil lead to plants.		
Lead uptake and resulting toxicity to plants appears to be related through the action of calcium. The concentration of calcium appears to show depressing effect on the lead uptake of the plant.		Wallace (1971)
Lead does not appear to accumulate in young, rapidly growing oat plants until they reach the early stages of maturity. The more advanced the stage of maturity, the higher the lead levels became in the vegetation studied.		Rains (1971)
Mercury:		
Mercury has a strong affinity for sulfur, particularly for sulfhydral groups and proteins. Bound to proteins in a cell membrane, mercury may alter the distribution of ions electric charge potentials and thus interfere with the movement of fluids across the membranes.		Goldwater (1971)
It has been found that plants such as carrots, potatoes, turnips, lettuce, and beans grown in soil treated with organic mercury compounds accumulate very little in the edible parts of the plants.		Wallace et al. (1971)
Mercury enters in several ways, first by absorption from the soil or mercury in folier sprays, dust, rain, or in vapors exhaled by the soil under day-night temperature gradients may enter the leaf tissue. Plants both inhale and exhale gaseous mercury through the stomata.		Lagerwerff (1972)
Molybdenum:		
Average molybdenum content which appears to produce toxicity for animals in many forage plants ranges:	10 - 26 ppm	Cunningham et al. (1953)
Molybdenum toxicity for livestock from plants is usually observed when concentrations exceed:	10 ppm	Hewitt (1963)
Legumes are able to absorb amounts of molybdenum harmful to cattle from soils that contain as little as 1.5 - 5.0 ppm total molybdenum.		Barshad (1948)
Molybdenum has been found to be an essential element for most plants. The tissue concentration requirement appears to be in a range of:	0.5 - 5 ppm	Gupta (1969)
Pasture plants considered toxic to cattle and sheep usually contain in excess of:	10 ppm	
Most plants appear to tolerate relatively high levels of tissue-bound molybdenum. No toxicity was observed in alfalfa at tissue concentrations of:	372 ppm	

	Concentration	Reference
Molybdenum is required in all plants for protein synthesis and symbiotic nitrogen fixation in legumes. Molybdenum is essential in the enzyme reductase which reduces nitrate to nitrite in the process of protein synthesis.		Boswell & Anderson (1969)
Optimum tissue levels of molybdenum for plants grown on sandy, clay-loam soils appears to be as follows:		Gupta (1970)
alfalfa:	0.12 - 0.46 ppm	
red clover:	0.46 - 1.08 ppm	
timothy:	0.14 - 0.17 ppm	
brussel sprouts:	0.11 - 0.22 ppm	
spinach:	0.15 - 0.24 ppm	
Injury from molybdenum appears in tomato plants at concentrations which exceed:	10 ppm	Arnon & Stout (1939)
Molybdenum when applied to soil at the concentration of 5 ppm has caused orange discoloration in flax with stunted root and plant growth. It was concluded that molybdenum is intimately associated with the regulation of the effects of manganese, zinc, copper, nickel, and cobalt on the physiological availability of iron to the plant.		Millikan (1947)
It appears that for most vegetation the essential level of tissue molybdenum is:	0.02 ppm	Piper (1940)
Molybdenum serves in plants as a catalyst in enzyme systems that function in reducing nitrate to ammonium in preparation for the synthesis of amino acids in proteins. As far as is now known, toxicity of molybdenum enters the agricultural picture only in relation to livestock.		Bear (1957)
No injury to most plants is seen even where the molybdenum concentration exceeds:	100 ppm	Allaway (1968)
The uptake of molybdenum by plants is reduced by sulfur since sulfur and molybdenum are two divalent ions of approximately the same size. Sulfur thus appears to inhibit molybdenum utilization within the plant. The effect appears to take place at the sight of uptake on the plant roots. Copper also appears to interfere with the role of molybdenum in the enzymatic reduction of nitrates causing molybdenum deficiency symptoms in plants.		Olsen (1972)
Molybdenum toxicity symptoms in alfalfa, if such can exist, are unknown at present.		Dye (1962)
Oat plants appear essentially normal with concentrations of:	50 ppm	Hunter & Vergnano (1953)
Slight chlorosis was observed in oats with the leaf tips showing a red-yellow color at molybdenum concentrations of:	100 ppm	

	Concentration	Reference
The size of the root structure of oat plants appears to be reduced at levels of:	200 ppm	
Only concentrations of molybdenum at 200 ppm appear to alter the major nutrient status of oat plants.		
Nickel:		
Nickel absorption by plants has been observed to damage the roots. In tomatoes, nickel absorption damaged the root system causing a reduction in the absorption and translocation of all other nutrient elements in the study.		Knight & Crooke (1956)
Nickel appears to be translocated in the conducting system of plants and moves to the areas of greatest metabolic activity where it becomes concentrated.		Vergnano & Hunter (1953)
Nickel sulfate solutions have shown a marked stimulatory effect on the germination of pea, bean, wheat and castor seeds when applied at concentrations of:	26.3 ppm	Choudhuri & Bhatnogar (1952)
The germination of these seeds was adversely affected at levels of:	<26,000 ppm	
Seed treatments with nickel appear to produce maximum growth of wheat shoots and roots at concentrations of:	100 ppm	Tsui (1955)
Growth appears to be inhibited at levels of:	250 ppm	
Nickel appeared to be highly toxic to buckwheat seedlings when applied at a concentration of:	5.87 ppm	Cotton (1930)
Nickel appears to suppress the growth of soybeans. Growth suppression appears to be due to deficiencies of both phosphorus and iron which were caused by the addition of excessive nickel. Nickel treatments appeared to reduce the total iron content of various plants.		Roth et al. (1971)
Nickel causing toxicity in oat plants did not markedly reduce the total iron content of plants. It appeared that nickel toxicity may cause a localized iron deficiency within plants rather than a total reduction of iron concentration.		Crooke & Knight (1955)
There appears to be a reciprocal relationship between iron and nickel content of leaves. Nickel is reduced by high concentrations of iron in solution and the iron content is reduced by high concentrations of nickel.		Crooke et al. (1954)
The severity of nickel toxicity to oat plants appears to increase with increasing manganese concentrations. The action of the two metals appear to increase the absorption of iron by the plant but decrease its metabolism.		Williams (1967)

	Concentration	Reference
One of the main toxic symptoms produced by nickel is the chlorosis or yellowing of leaves usually followed by necrosis. Other symptoms include stunted growth of the root and shoot, deformation of various plant parts, unusual spottings, and in extreme cases, death of the plant. Nickel appears to regulate mineral metabolism and enzyme activity in plants. At non-phytotoxic levels, it has been shown to increase yield of some crops. Nickel has not been ranked as an essential in plant nutrition.		Mishra & Kar (1974)
From the literature, it appears that marginal toxicity in oat plants will occur at tissue levels of approximately:	50 - 150 ppm	Anderson et al. (1973)
Selenium:		
Selenium in nutrient solution has been toxic to wheat plants in the absence of sulfur at concentrations of:	0.1 ppm	Hurd-Karrer (1934)
Toxicity appears to be eliminated with the addition of sulfur. It has been shown that sulfur concentrations of 192 ppm prevent plant injury by selenium at concentrations of:	16 ppm	
Selenium has shown stimulation of growth in wheat plants when applied to concentrations of:	0.4 ppm 1.0 ppm 2.6 ppm	Perkins & King (1938)
Toxicity in wheat occurred at:	6.4 ppm	
It appears that various plants which have high sulfur requirements also store relatively large quantities of selenium. Some of these crops are broccoli, cabbage, cauliflower, mustard and onions.		Hurd-Karrer (1937)
Visual symptoms of excess selenium have never been observed in field plants growing on naturally seleniferous soils. Most all visual toxicity symptoms have been produced in greenhouse experiments by the addition of selenite, selenate, or organic selenium to the root medium. Toxicity symptoms in cereal grains usually appears as a snow white iron chlorosis of the leaves. Stunting of growth is indicative of less severe injury.		Gange (1966)
In wheat, a pinkish coloration of selenite-injured roots accompanies the chlorosis symptoms.		
The literature contains very little information concerning data of what threshold values of selenium exist for various plants.		
Comparative toxicity of selenates and selenites to plants depend on the concentration of available sulfate. Toxicity of all selenates decreased progressively with the increasing sulfate sulfur while that of selenites was greater with higher concentrations of sulfate.		Hurd-Karrer (1937)

	Concentration	Reference
Toxicity of selenium to wheat and buckwheat appears to be proportional to the concentration added as sodium selenite to soil cultures and solution cultures. Decreased growth rate occurred with application of:	1, 2, & 4 ppm	Martin (1936)
Extreme chlorosis and premature plant death occurs at:	8, 16, 32, & 64 ppm	
Selenite was observed to be more poisonous to animals than plants. Buckwheat plants that exhibited no symptoms of injury except for slight dwarfing, contained enough selenium to produce death in rats in nine weeks of dietary intake.		
Plants have been put into three groups by Miller and Byers according to the ability to assimulate selenium. Group 1: plants with limited tolerance, up to 5 ppm. Group 2: plants with a moderate tolerance, up to 30 ppm. Group 3: plants with very high tolerance to selenium.		Fleming (1965)
Most grasses, clovers, and garden vegetables are included in Group 1. Most all cereal grains are in Group 2.		
Vanadium:		
Vanadium oxide as ammonium metavanadate showed the following effects on rice seedlings:		Chiu (1953)
increased growth:	150 ppm	
toxicity symptoms:	500 ppm	
plant death:	1000 ppm	
There appears to be no reports in the literature indicating either deficiency of toxicity of vanadium in vegetation under field conditions. Vanadium appears to have some function in the growth or nitrogen fixation processes of certain soil microorganisms but its essentiallity for crop plants has not been conclusively demonstrated.		Pratt (1966)
In studies using excised barley roots, it was noted that the rate of uptake of vanadium by the plant was highest at an acid pH but dropped to very low levels at alkaline pH levels. It does not appear that vanadium is actively absorbed by plant roots.		Welch (1973)
Vanadium in nutrient solutions is commonly harmful to plants at concentrations of:	10 - 20 ppm	Cannon (1963)
Vanadium content of above-ground parts of plants rooted in highly calcic soils is very high. The absorption and translocation of vanadium by several plant species was found to parallel that of selenium.		

	Concentration	Reference
Plant species that absorb large amounts of calcium are most tolerant of high vanadium soils, due to vanadium being precipitated in the roots.		
Zinc:		
It appears that the uptake of zinc by barley is counteracted by phosphorus applications at various stages of growth. It is suggested that in areas where regular phosphorus applications to soil are necessary, a zinc deficiency in vegetation may result.		Montsara (1973)
From the literature, it appears that in a variety of plants, deficiency levels are characterized by zinc concentrations of less than:	20 - 25 ppm	Chapman (1966)
Ample levels commonly fall in a range of:	25 - 150 ppm	
Excessive zinc concentrations in plants generally exceed:	400 ppm	
Alfalfa has shown symptoms of zinc deficiency at tissue concentrations of:	8 - 13 ppm	Millikan (1953)
In zinc toxicity studies with oat plants, it was observed that toxicity symptoms appear in mature leaves at zinc concentrations of:	1700 - 7500 ppm	Hunter & Vergnano (1953)
In studies with young oat plants, it was observed that deficiency symptoms would appear at tissue zinc concentrations of less than:	20 ppm	Wood & Sibly (1950)
Tomatoes grown in a solution medium have shown symptoms of zinc toxicity in leaves at concentrations of:	526 - 1489 ppm	Lyon et.al. (1943)
It is postulated that zinc is necessary for chlorophyll formation and growth of plants.		Camp (1945)
Corn plants show moderate symptoms of deficiency at zinc tissue concentrations of:	9 ppm	Hiatt & Massey (1958)
Normal appearing corn plants were found to contain:	16 ppm	
In laboratory studies, it was shown that different varieties of soybeans exhibit a striking variation in reaction of zinc concentrations in slightly acid or neutral nutrient solutions. The degree of plant damage from zinc appears to increase with the decreasing pH of the solution. That is, the more acid the solution, the greater the degree of plant damage caused by zinc.		Earley (1943)
Zinc toxicity problems in plants has been overcome by liming the soil.		Bear (1957)
Zinc in nutrient solutions has been shown to greatly increase plant growth and dry matter yield at concentrations of:	0.5 mg/liter	Jelenkovic (1969)

	Concentration	Reference
Zinc was applied to soil at the rate of 11 kg/ha for six successive years without producing toxic effects in soybeans. The high tolerance was partly attributable to a decrease uptake in zinc at near neutral levels of pH of the soils. It was indicated that very high concentrations of zinc do not increase the concentrations in soybean seeds to levels that would preclude their use as animal feed.		Martens et al. (1974)
In plants, it appears that root absorption of zinc is greater than the zinc translocated to the tops of plants. It also appears that the uptake of iron is depressed with the application of high concentrations of zinc salt or combined zinc and iron salts.		Lopez & Graham (1973)
It is postulated that alkaline earth cation effects are important in the zinc nutrition of plants in soil and solution cultures in that the addition of such substances may result in zinc deficiency in plants where none previously existed.		Chaudry & Loneragan (1972)
In field experiments, seedlings growing in soil ranging in zinc concentrations from 100-300 ppm showed no signs of toxicity, even with the folier levels reaching to:	2120 ppm	Bauchauer (1973)
In experiments with grasses and clovers, it appears that zinc content in plants varies with species and stage of maturity. Zinc contents of grasses decreased with increasing maturity.		Fleming (1965)
Experiments show that copper appears to strongly inhibit the absorption of zinc by barley roots. It appears to be possible that copper and zinc compete for the same absorption sites on plant roots.		Schmid et al. (1965)
Fluoride:		
Fluorides originating in the soil tend to accumulate in the roots of plants. High concentrations of root-acquired fluoride causes necrosis of the internal areas of leaves of some plant species. Airborne, leaf-acquired fluoride causes marginal and tip necrosis of leaves.		McClure (1969)
Leaves remove gaseous fluoride from the air with accompanying accumulation in the tissue. Acute fluoride injury symptoms: Occurrence of necrotic tissue along margins and tips of leaves along with possible streaking or spotting. The effects vary with the species of plant. In chronic fluoride injury, a loss of chlorophyll occurs resulting in a chlorotic or mottled pattern.		

	Concentration	Reference
Plants low in calcium appear to be more severely damaged by fluoride.		
Soil pH appears to play a role in the toxicity of fluoride to vegetation. An acidic pH in soil requires small concentrations of fluoride to produce injury. All vegetation studied in soil pH ranges of 4.5 to 6.5 were injured by fluoride concentrations of:	360 ppm	Prince et al. (1949)
Concentrations of fluorides causing toxicity vary with type of soil, pH, and plant species.		
Evidence that fluorine performs a vital function in the nutrition of plants has not been produced. Herbage plants are usually low in fluorine which tends to reflect the limited capacity of most plant species to absorb fluorine from the soil.		Underwood (1962)
The presence of abnormally high fluoride concentrations in plant tops with low concentrations in the roots indicates that atmospheric fluoride is the principle source of the element to vegetation. A reverse order concentration indicates the soil as the source of fluorides in investigative studies.		Brennan et al. (1950)
Many species of plants have shown symptoms of chronic fluoride toxicity after extended periods of exposure to hydrogen fluoride in the air at concentrations of:	5 - 7 ppb	Brewer (1966)
Interveinal chlorosis appears to be a primary symptom of chronic fluoride toxicity.		
Corn leaves when exposed to:	5.0 ppb	Adams et al. (1957)
of hydrogen fluoride have shown toxicity symptoms with actual leaf concentrations of approximately:	180 ppm	
The primary danger of fluoride injury to plants appears to depend upon the absorption of fluoride into the tissue. Fluoride gases are more readily absorbed than solid fluoride compounds deposited on leaf surfaces. Injury develops under widely fluctuating concentrations or brief exposure to high concentrations.		Pack & Adams (1966)
Fluoride containing gases are much more toxic to vegetation than equivalent atmospheric concentrations of other phototoxic gases.		Adams (1956)
Fluoride has been observed to accumulate in vegetation at atmospheric concentrations of:	0.1 - 0.7 ppb	
Data indicates that fluorine is a cumulative systemic poison in vegetation.		

Sulfur:	Concentration	Reference
Visual symptoms of bean and tomato seedling leaf injury have been observed after 48 hours of fumigation with sulfur dioxide at a concentration of:	0.5 ppm	Solberg & Adams (1956)
Sulfur dioxide causes two types of injury to the leaves of plants. Acute injury shows marginal or interveinal collapsed areas while chronic injury shows areas of leaf cell damage but not total collapse.		Thomas, M. D. (1958)
Various amounts of leaf destruction on alfalfa have been predicted experimentally at the following levels at 1-hour exposure:		Thomas & Hill (1935)
slight injury	0.94 ppm	
50% leaf destruction	2.1 ppm	
total leaf destruction	3.2 ppm	
One-hour exposure to sulfur dioxide may cause injury to the following plants at the indicated concentration levels:		O'Gara & Hendricks (1956)
Alfalfa:	1.2 ppm	
Barley:	1.2 ppm	
Wheat:	1.8 ppm	
Plant injury is any measurable response of a plant to air pollution. Damage is any identifiable and measurable adverse effect upon the desired or intended use of the plant.		Heggestad & Heck (1971)
Detectable injury to sulfur dioxide sensitive plants will occur under average conditions with a 4-hour exposure time and sulfur dioxide concentrations of:	0.5 ppm	Thomas (1961)
Acute injury to trees and shrubs has occurred after 7-hour exposure time of sulfur dioxide at a concentration of:	0.5 ppm	Scheffer & Hedgcock (1955)
Alfalfa and barley are among the most sensitive to ambient sulfur dioxide. Incipient damage markings on alfalfa under conditions of maximum sensitivity occur after one hour at a concentration of:	1.25 ppm	Middleton et al. (1958)
In experiments with sulfur dioxide and ozone, it has been observed that sub-injury threshold levels of each gas when mixed, caused plant damage greater than the additive effects alone. This suggests that this combination of pollutants lowers the threshold for plant injury and effects are synergistic.		Menser & Heggestad (1966)
Barley leaves exposed for 72 hours with sulfur dioxide showed symptoms of leaf necrosis at a concentration of: The addition of HF at .0009 ppm to the sulfur dioxide showed no additional leaf injury.	0.3 ppm	Mandl et al. (1975)
The degree of plant injury by		Whitby (1939)

	Concentration	Reference
sulfur dioxide at any given concentration level and period of exposure is highly dependent upon factors favoring stomata opening and photosynthesis such as relative humidity and light intensity at time of exposure.		
The degree of damage to vegetation by sulfur dioxide is associated with high humidity (>70%), moderate temperature (>40°F), high light intensity, adequate moisture supply, and wind stability for exposure periods of three hours or more, in addition to the ambient concentration of sulfur dioxide.		Holmes et.al. (1915)
Leaf destruction in vegetation is more directly dependent upon the amount of gas actually absorbed than on the concentration of sulfur dioxide gas in the air. Exposures which result in severe injury to given plants under any set of conditions are innocuous under others.		Middleton et al. (1958)
Exposures of sulfur dioxide after long duration on vegetation may cause toxicity to sensitive plants at concentrations of:	>0.4 ppm	Katz (1949)
Concentrations demonstrated to be in the range of non-influence have been reported as:	0.10 - 0.20 ppm	
Common small grain and vegetable crops have shown no symptoms of injury after 4-hour fumigation of sulfur dioxide at levels up to:	50 ppm	Tingey et al. (1971)
Plant injury has been observed when sulfur dioxide was mixed with nitrogen dioxide at levels of:	5 - 25 ppm	
Different plants vary widely in their susceptibility to injury by sulfur dioxide. Alfalfa and barley are the most sensitive.		Thomas et al. (1950)

The Effects of Selected Trace Elements on Animal Nutrition and Health

Arsenic:	Concentration	Reference
Arsenic is not considered essential for animal growth and reproduction. As retention and excretion depends on the arsenic compound and species of animal.		Underwood (1962)
Small amounts of arsenic in animal diets may counteract selenium toxicity.		Allaway (1968)
Primary danger of arsenic toxicity to livestock and humans is from plants contaminated by dust containing arsenic compounds.		Underwood (1962)
Arsenic in the form of arsenic acid shows little retention in the tissues of cattle and is not excreted into the milk. There is no established effect of this compound.		Peoples (1964)
Beryllium:		
The present occurrence of beryllium does not represent a factor in the health of domestic or wild animals. Beryllium dissolved in water or food supplies is not known to be of health significance unless very high experimental concentrations are achieved.		Tepper (1972)
Beryllium has been shown experimentally to induce rickets in animals. The phenomena appears to be related to the uptake of calcium and phosphorus from the gastro-intestinal tract and does not appear to be related to man. Tumors of the lung and bone have also been shown experimentally in animals with no apparent relationship to man.		Tepper (1972)
Cadmium:		
Chronic cadmium poisoning has occurred in a horse after long-term ingestion of hay and grasses containing: (incident report)	7.6 - 9.9 ppm	Goodman & Roberts (1971)
In a 12-week study, no toxic effect was seen in calves being fed a ration containing 40 ppm Cd, and 22.4 ppm zinc.		Powell et.al. (1964)
Cadmium content of all animal tissues was found to increase with increasing dietary cadmium intake. The high Cd intake was found to depress copper, iron, and manganese in various tissues. Zinc concentrations in animal liver and kidneys was seen to significantly increase at dietary Cd levels of:	15 ppm	Doyle & Pfander (1975)
The growth rate of young pigs is shown to decrease as a function of dietary cadmium level intake. Cessation of growth (in pigs): Calcium levels in the animal tissues were not affected by high cadmium intake. Toxicity symptoms appear primarily where there are high levels of cadmium and deficient levels of calcium.	1350 ppm	Cousins et.al. (1973)
Selenium has been shown to exhibit a protective effect against cadmium toxicity effects in animal experiments. Increasing the concentration of zinc tends to reduce the protective effect of selenium.		Mason and Young (1967)

Chromium:	Concentration	Reference
A review of the literature indicates that there have been no episodes comparable to those of selenium or arsenic, etc. in which farm animals have been poisoned by excess chromium intake due to environmental contamination.		Smith (1972)
Chromium has been classified as a low toxicity element meaning exposure required for detrimental effects to the animal from dietary intake must be:	>100 ppm	Allaway (1968)
Chromium in the hexavalent form is especially toxic to animals at high levels.		
Copper:		
Normal animal diet requirement of copper:	1 - 10 ppm	Allaway (1968)
However, this is dependent on accompanying levels of Mo in the diet. Dietary levels of Mo of 10 - 20 ppm, are nearly always associated with some evidence of disturbed copper metabolism in ruminant animals.		
Chronic copper poisoning of calves, with death resulting in 20 and 21 weeks has occurred at a dietary concentration of:	500 ppm	Todd & Thompson (1965)
Symptoms: hemalytic crisis and induced jaundice.		
Adult cattle will tolerate:	5 gm/day	
Calves will tolerate:	1 gm/day	
Calves can tolerate dietary levels of:	72 and 115 ppm	
Phases of copper poisoning in animals (1) tissue accumulation (2) development of toxicity symptoms. Site of tissue accumulation is the liver.		Todd (1962)
Toxicity signs may develop when liver concentration reaches:	4000 - 5000 ppm	
Sheep are the most susceptible animal to copper toxicity with calves being next. Death in sheep has occurred in one to two months at levels of intake:	1 gm/day copper sulfate	
Chronic toxicity in sheep can develop over long periods in concentrations of:	30 ppm	
Death from chronic copper poisoning of sheep has occurred at:	35 ppm	
In diets very low in molybdenum, toxaemic jaundice has occurred at:	15 - 20 ppm	
Very young calves have shown toxicity symptoms at:	115 ppm	
Death has occurred in pigs on feed concentrations of:	130 ppm	
Excessive intake of molybdenum and sulfate limit copper storage in the liver and are used effectively in reducing the toxicity of copper.		
Levels of copper in herbage as related to the needs of grazing animals.		Gladstone et al. (1975)
deficient	<3 ppm	
marginal	3 - 5 ppm	
adequate	>5 ppm	

	Concentration	Reference
Cadmium appears to be antagenistic to copper. High Cd levels interfere in the protein synthesis necessary for copper absorption, which decreases copper contents of maternal and fetal tissues.		Hennig et al.
Toxic syndrome in livestock chronic copper poisoning: (1) period of passive accumulation in tissues: several weeks to a year, usually with no symptoms. (2) toxic phase: hemalytic crisis. Animal becomes dull, lack of appetite, excessive thirst, jaundice.		Todd (1969)
Excessive zinc and iron added to diets of copper-poisoned animals causes a reduction in accumulated copper and receding symptoms of copper toxicity.		Suttle and Mills (1966)
Molybdenum and copper are antagenistic in animal metabolism. Cu controls the pathological effects of Mo and Mo inhibits copper deposition in the liver.		Cunningham (1950)
One of the primary symptoms of high copper intake in pigs is iron deficiency. Copper appears to impair iron absorption from the gastrointestinal tract. Toxicity in hogs has appeared at:	250 ppm	Gipp et al. (1974)
Lead:		
Toxicity of lead compounds to cattle and horses have been observed when concentrations in total ration dry matter have reached:	150 ppm	Hammond & Aronson (1964)
No toxic effects have been observed in cattle after two years on a total lead intake of:	5 - 6 mg/kg dry wt.	Allcroft (1950)
Toxicity has been observed in horses on pasture grasses which contain a dry weight concentration of: All domestic species of livestock with lead poisoning exhibit varying degrees of derangement of the central nervous system. Chronic lead poisoning symptoms: Cattle: Blindness, grinding of the teeth, moving in a circle and ataxia. Sheep: Depression, anorexia, abdominal pain and usually diarrhea.	80 ppm	Aronson (1971)
Chronic lead poisoning symptoms in the horse: depression, stupor, knuckling at the fellocks, laryngeal paralysis and anemia.		Clarke & Clarke (1967)
Apparent lethal dose of lead oxide to a mature cow appears to be:	4.8 mg/kg body wt.	White et al. (1943)
Lead is one of the most common causes of poisoning in livestock in the U.S. The toxicity of lead varies with many factors and species of animals and within individual species.		Buck (1970)

	Concentration	Reference
Concentrations of lead acetate causing death in young cattle:	200-400 mg/kg body wt.	
Older cattle and sheep:	600-800 mg/kg body wt.	
Lead poisoning in cattle has developed in 6 - 8 weeks on total daily intake of:	6 - 7 mg/kg body wt.	
Lead is a cellular poison and the clinical signs are usually manifested by some form of central nervous system disorder.		
Death of young calves up to 4 months in age may result from daily lead acetate intake of:	0.2-0.4 gms/kg body wt.	Allcroft & Blaxter (1950)
Non-pregnant sheep and cattle can survive up to one year without toxicity symptoms on a total daily intake of:	5 mg/kg body wt.	
Death has resulted in cattle after 220 days on dietary intake levels of:	8 mg/kg body wt.	
Data indicates that pregnant sheep are more susceptible to lead and that abortion may follow continuous ingestion of lead in quantities which appear to be safe for non-pregnant sheep.		
Lead poisoning in animals and man has been seen to cause anemia, fatigue, weight loss, chronic renal disease, and neurological alterations manifestes as intestinal colic, neuropathy and encephalopathy. Antagonistic effects in biological systems have been observed for lead versus Mn and Mo, zinc, copper and iron and iodine.		Vallee & Ulmer (1972)
Lead poisoning in cattle and sheep has been observed on dietary intake of forage materials containing:	25 - 46 ppm	Dunn & Bloxan (1932)
Lead contamination of soils in the area of a smelter has been linked to lead toxicity in horses even though ambient air and drinking water concentrations of lead were within acceptable limits		Schmitt et al. (1971)
Mercury:		
Methyl mercury accumulates in animal tissue because of long retention time in tissue. Most of the mercury found in animal tissue is methyl mercury.		Hammond (1971)
There is considerable risk for accumulation of methyl mercury in the tissues of mammals with prolonged exposure to methyl mercury compounds. The risk is due to very slow tissue elimination and a biological half-life which varies from 20 - 70 days in different species.		Derglund & Berlin (1969)
Depending on the species, central nervous system disorders with neurological symptoms seem to appear at mercury concentrations in the brain tissue of 8 mg/gram or more.		
Little is known about the dose level of mercury at which the first detectable toxicity signs or changes first appear.		

	Concentration	Reference
No qualitative or quantitative data has been found concerning mercury poisoning for animals exposed to typical environmental conditions.		Stahl (1969)
Dogs have shown no signs of mercury poisoning after forty days of exposure to an aerial concentration of:	3000 $\mu g/m^3$	Frazer et al. (1934)
The dogs showed central nervous system effects after forty days of exposure to an aerial concentration of:	6000 $\mu g/m^3$	
Death has been the result in dogs after exposure to mercury vapor at concentrations between:	6000-20,000 $\mu g/m^3$	
Molybdenum:		
Toxicity and death in cattle has occurred of forage concentrations of: Typical symptoms include severe diarrhea, emaciation, anemia, fading of hair color, excessive craving for salt, all of which usually end in death. Evidence has been obtained to show that in the early stages of molybdenum intoxication, molybdenum may pass through into the milk of cattle and affect young calves.	25.0 ppm	Cunningham et.al. (1953)
Dietary molybdenum in the absence of sufficient copper appears to create typical symptoms of molybdenum toxicity with accompanying loss of weight, scouring, and reduced feed consumption. Molybdenum appears to complex copper and that copper in the complex state is biologically inactive in the animal.		Clawson et.al. (1972)
Molybdenum is rapidly absorbed from the intestinal tract of animals. This applies particularly to water soluble forms.		Underwood (1962)
Molybdenum is excreted mainly in the urine of animals. Sulfates by some mechanism appear to reduce molybdenum retention in the tissues of cattle presumably through the increase of urinary excretion.		
Molybdenum in very small concentrations has been shown to produce a significant growth response in lambs. This response is believed to be due to the action of molybdenum in increasing cellulose degradation by rumen microorganisms.		
One of the features of severe molybdenosis known as teart in cattle remains obscure, this is primarily the mechanism of the protective action of copper. The tolerance of animals to molybdenum appears to be affected by the chemical form in which the element is administered, the copper status and intake of the animal, and the organic sulfate content of the diet.		

	Concentration	Reference
Horses and pigs appear to be among the most tolerant of high forage molybdenum concentrations. No ill effects were seen after three months of feed levels of:	1000 ppm	
However, the effect of molybdenum depends on the copper and sulfate status of the diet.		
It has been shown that chronic copper poisoning associated with extremely high liver copper levels in sheep appears under conditions of moderate copper intakes and very low intakes of molybdenum and sulfate.		
It is felt that molybdenum concentrations at levels greater than 2 ppm in forage may be of importance in molybdenum induced hypocuprosis in cattle.		Allaway (1973)
Specific symptoms of molybdenum intoxication in cattle were observed where the native vegetation contained molybdenum concentrations:	>20 ppm	Barshad (1948)
No symptoms were observed with forage concentrations of:	<10 ppm	
Molybdenum toxicity in ruminants appears to involve not only an excess of molybdenum, but also low levels of copper and high sulfur-sulfate concentrations in forage. Copper supplementation of the diet appears to be only moderately effective in reducing toxicity dangers in cattle, but subcutaneous injections of copper-glycinate appears to afford protection for periods of 3 - 6 months.		Dye & O'Harra (1959)
Sulfate appears to increase excretion of molybdenum in animals.		Dick (1956)
It is possible for copper reserves of livestock to increase on low copper intakes when molybdenum and sulfate content of the diet are low and conversely for animals copper reserves to be depleted even to a level of clinical copper deficiency when copper intake is normal and molybdenum and sulfate intake are high.		
The concentration in forage vegetation which appears to cause toxicity problems of molybdenum in grazing animals is reported as a range of:	10 - 20 ppm	Kubota et al. (1967)
Molybdenum appears to exhibit a toxicity at concentration levels very similar to that of arsenic. In monogastric animals, only slight toxicity appeared at intake levels of:	50 ppm	Frank & Moxon (1937)
From the literature reviewed, the upper limit of molybdenum concentration in vegetation for good animal nutrition appears to be in a range of:	5 - 10 ppm	James et al. (1968)
The desirable range of molybdenum content of forage between nutritional deficiency in the crop and toxicity in livestock is quite narrow.		

	Concentration	Reference
Severe symptoms of molybdenum toxicity were observed in cattle grazing on native pastures which contained concentrations of molybdenum from normal to 160 ppm.		Becker et.al. (1965)
Molybdenum appears to be essential in the animal diet in that it has been found as a constituent of the enzyme xanthine oxidase, which appears to play an essential role in purine metabolism in animals.		Maynard & Loosli (1969)
Molybdenum toxicity appears to occur in livestock on pastures with vegetation containing levels of more than:	14 ppm	Muir (1941)
A potential hazard may exist where pastures contain:	7 - 14 ppm	
Toxicity was observed in cattle at intake levels of:	10.3 ppm	Britton & Goss (1942)
The concentration range for vegetation where the toxicity occurred:	6 - 36 ppm	
Molybdenosis has been reported in Nevada on daily dietary intakes as follows:		Dye (1962)
cattle:	5 - 6 ppm	
sheep:	10 - 12 ppm	

Nickel:

	Concentration	Reference
There have been no reports of widespread damage to the environment by nickel compounds in the atmosphere or elsewhere, and nickel does not appear to be a problem with respect to its effects on vegetation, domestic animals or wildlife.		Smith (1972)
Studies indicate that 90% of the ingested nickel in dogs is excreted in the stool and 10% eliminated in the urine. A complete balance study in a dog before and after exposure to nickel carbonyl indicates that virtually all of the nickel is excreted within six days and there is no significant retention of nickel in the body.		Tedeschi & Sunderman (1957)

Selenium:

	Concentration	Reference
Growth retardation and death has occurred in rats and guinea pigs after several weeks on a diet of wheat containing:	8 - 10 ppm	Nelson et.al. (1933)
Symptoms of intoxication from selenium were observed when blood levels began to exceed:	3.0 ppm	Maag et al. (1960)
Loss of appetite and depression in cattle began to appear at selenium blood levels of approximately:	4.0 ppm	
Alkali disease appears to be the predominant animal disease in areas where seleniferous soils are formed. The disease results from the consumption of grains and forages for a period of several days or weeks that contain up to:	25 ppm	Moxon & Rhian (1943)
Symptoms include dullness and lack of vitality with animals becoming emaciated, stiff, and lame. The prominent symptoms in horses and mules appears to be the loss of long hair from the mane and tail.		

	Concentration	Reference
Symptoms of selenium toxicity in cattle: early stages show a dullness and lack of vitality. There appears to be a stasis of the gastrointestinal tract. There also appears to be considerable abdominal pain with grunting, grating of teeth and salivation. Animals have been observed to wander, often aimlessly in circles. There may be impairment of vision. Prior to death, paralysis may result.		Beath et al. (1934)
In poultry, it was found that the feed consumption and growth of chicks is reduced when a ration is fed which contains:	8.0 ppm	Moxon (1937)
Infertile eggs and deformed embryos have resulted when hens received a ration containing selenium at levels of:	3.5 ppm	
From a review of the literature, it appears that chronic toxicity in various animals will occur at the following selenium levels in feeds:		Thacker (1961)
Chickens:	5 - 8 ppm	
Cows:	5 - 40 ppm	
Dogs:	7.2 - 10 ppm	
Rats:	5 - 15 ppm	
Sheep:	10 mgs/day	
Swine:	10 - 15 ppm	
Tests show the administration of subtoxic levels of selenium produce an increase in clean fleece weight, fiber thickness, and body weight in sheep. Data suggests selenium may be an essential nutrient for wool and body growth in sheep.		Slen et al. (1961)
In chronic cases of alkali disease, there appears to be a loss of hair from the mane and tails in horses, tails in cattle, and a general loss of hair in swine. Hoofs slough off, lameness occurs, food consumption decreases and death may occur by starvation. Soil considered to be potentially hazardous to livestock is any soil which contains in excess of:	0.5 ppm	Maynard & Loosli (1969)
Chronic toxicity is caused by rations as little as:	8.5 ppm	
Young animals are especially susceptible and growth is retarded with levels too low to cause other evident symptoms.		
Selenium is essential in the diet of livestock to prevent the deficiency syndrome of white muscle disease. The critical required level of selenium in the animal in order to prevent white muscle disease has been stated as:	0.1 ppm	Allaway & Hodgson (1964)
In laboratory experiments with rats receiving a subtoxic dose of sodium selenite, it has been noted that the injection of arsenite showed a marked increase in the excretion of selenium into the gastrointestinal tract.		Ganther & Baumann (1962)
From a study in South Dakota, it has been observed that cattle have shown symptoms of chronic selenium toxicity on grass diets containing selenium at levels of:	10 - 20 ppm	Moxon (1958)

Vanadium:	Concentration	Reference
Vanadium occurs in all animals and is accumulated in large amount by ascidians and holothuroidians. Vanadium is probably essential to vertebrates and has been shown to decrease dental caries in animals and children. Vanadium appears to inhibit the biosynthesis of cholesterol in both animals and man.		Cannon (1963)
In studies with laboratory animals receiving suboptimal diets, vanadium pentoxide caused toxicity at concentrations of:	100 ppm	Stokinger (1963)
In animals receiving optimal diets, toxicity appeared at concentrations of:	1000 ppm	
Zinc:		
No ill effects were observed in lactating cows when fed a diet over a six week period with a daily zinc concentration of:	1269 ppm	Miller et al. (1965)
Weight gain and feed consumption were reduced in cattle receiving a diet containing:	900 ppm	Ott et al. (1966)
No adverse effects were observed in cattle receiving a dietary zinc concentration of:	500 ppm	
When cadmium was given in concentrations of 350 ppm, there appeared to be reduced zinc absorption in calves. Cadmium appears to be a strong anti-metabolite for zinc. Whether the effect in zinc absorption is direct or indirect is unknown.		Powell et.al. (1967)
Zinc is an essential element in animal nutrition. Studies indicate the primary agricultural problem with zinc is that of livestock and plant deficiencies. Prevention of zinc deficiency in cattle requires a dietary level of approximately:	8 ppm	Maynard & Loosli (1969)
Zinc intoxication in pigs has been observed at dietary concentrations of:	2000 ppm	
Death has resulted in lambs receiving a dose of zinc at concentrations of:	4 - 6 grams	Ott et al. (1966)
Zinc concentrations in plants have a low availability to animals. This has been attributed to the presence of insoluble complexes of zinc with calcium and phytic acid in plants.		Allaway (1968)
On studies concerning zinc, it was noted that in one example, zinc deficiency was induced in calves receiving a purified diet with a zinc content of:	<10 ppm	Kubota & Allaway (1972)
It has been estimated that fattening rations used for optimum rates of gain for steers should contain zinc levels of:	40 ppm	

Fluoride:	Concentration	Reference
Symptoms of fluorosis appear to be difficulty in locomotion, raggedness of coat, reduction of milk yield, and abnormal skeletal development. Morphological changes are manifested in the bones and teeth. Bones become soft and teeth become pitted and eroded. Toxicity depends on: nature of the fluoride compound, duration and mode of intake, along with the species and age of the animal.		Pierce (1939)
Chronic fluorine toxicosis is the type most commonly observed in livestock. The onset appears as a chronic debilitating disease. Because of the nature of the symptoms, it appears to be impossible to define a precise point at which excessive continual consumption of fluorides induce chronic fluorosis. Fluoride toxicity can be observed by the development of fluorotic dental lesions in animals during tooth development. Fluorides are stored in the bones and over a period of time will cause structural changes. Bone lesions are characteristic of chronic fluorosis. Chronic fluorosis has been observed in dairy cattle after 2 1/2 years of daily dietary intake of:	93 ppm	Shupe (1969)
Chronic fluorosis has also been observed in dairy cattle after 4 1/2 years on a daily intake of:	49 ppm	
From data on cattle, the soft tissues do not appear to retain increased dietary fluorides with the exception of the kidney. The bones appear to store fluorides until they become saturated. At the bone saturation point, the excess fluorides begin to spill over into the soft tissues and the early symptoms of fluoride toxicosis begin to appear. This time period for bone saturation to take place has been called the lag period.		Phillips & Suttie (1960)
The margin of concentration ranges of dietary intake of fluorides between physiologic benefit and toxicity is very small. Toxicity resulting from fluorides is usually from three principal sources: water, feed supplements, and ingestion or inhalation of fumes and dust from industrial sources. The safe and harmful levels of dietary fluorine depend upon type compound, time duration of ingestion, animal species, and the age of the animals.		Underwood (1962)
Grazing animals receive fluoride principally from fluoride dust on foliage. The borderline forage concentration for possible fluorosis in dairy cattle appears to be in the range of:	30 - 40 ppm	Hodge & Smith (1972)

	Concentration	Reference
Animals may be subject to fluoride toxicity when grazing on vegetation with a level of approximately:	50 ppm	Phillips et al. (1955)
Fluoride injury to animals depends upon their total fluoride intake rather than the fluoride concentration in any particular portion of the diet. Contamination of forage by wind blown soil dust or soil splash during heavy rain and consumption of soil under close grazing conditions may contribute appreciably to fluoride injury to animals in areas where high soil fluoride exists.		Pack & Adams (1966)
A concentration of fluorine in in the total ration of animals which has been termed as borderline between safe and unsafe dietary intakes is given at a level of: (on a dry weight basis)	100 ppm	Mitchell (1942)
The normal dietary ingestion of fluoride in cattle of dry forage matter is listed at:	15 ppm	Shupe et al. (1964)
Concentrations of fluorides in feed stuffs which have shown toxic effects are as follows:		
borderline symptoms:	30 - 40 ppm	
moderate symptoms:	40 - 60 ppm	
severe symptoms:	60 - 109 ppm	
Toxicity at these concentrations require ingestion over long periods of time.		
Fluorine tolerances in various livestock diets of breeding and lactating animals:		Shupe (1969)
dairy and beef heifers:	30 ppm	
dairy cows:	30 ppm	
beef cows:	40 ppm	
sheep:	50 ppm	
swine:	70 ppm	
Fluorine tolerance in finishing animals with average feeding periods:		
beef and dairy heifers:	100 ppm	
dairy cows: approximately	100 ppm	
beef cows: approximately	100 ppm	
sheep:	160 ppm	
Cattle will withstand an ingestion of soluble fluoride in total feed up to levels of approximately:	75 ppm	Elmslie (1936)
Sulfur:		
Pathological changes have been observed in the lungs of laboratory animals after two weeks exposure to sulfuric acid mists at a level of:	1 mg/m^3	Bushtueva (1962)
Green plants are the primary source of sulfur for animals which are unable to form proteins from inorganic sulfates. Inorganic sulfur cannot be utilized by animals and sulfur in the elemental form is toxic.		Gilbert (1951)
Sulfuric acid aerosols are more important factors in causing ill effects to animals than is sulfur dioxide.		Middleton (1966)

The Effects of Selected Trace Elements on Human Health

Arsenic:	Concentration	Reference
Most toxic of the arsenic compounds is arsenic gas and can cause death at:	100 ppm	Lee (1972)
Toxicity symptoms in humans: weakness, abdominal pain, generally non-specific complaints. Symptoms associated with occupational exposure: dermatitis, perforation of nasal septum, and occasional ulceration of skin.		
Chronic effects of arsenic on humans: dermatitis, hyperpigmentation, conjunctivitis, nasal irritation, edema of eyelids, hoarseness, loss of hair, CNS disorders, nausea, vomiting, abdominal pain, hypoplastic anemia. Acute toxicity effects: headache, dizziness, garlic odor of breath, chills, tingling of hands and feet, nausea, vomiting, abdominal cramping, pulmonary edema, hepatomegaly, hematuria, aligresia, albumurea, leukocytosis.		International Technical Information Institute (1976)
Beryllium:		
When beryllium or its compounds are present as airborne particulates of respirable size, a hazardous situation may exist since inhalation of beryllium materials has been associated with both acute and chronic illness in humans. Potential problems of beryllium are related to concentration and size of particles in industrial and ambient atmospheres. All reported cases of beryllium disease have arisen from industry. The industries are: beryllium extraction, fluorescent lamp production, neon lamp industry, x-ray tube production, nuclear energy industries, alloy production, metal working, and electron tube production.		Tepper (1972)
Acute beryllium disease in humans usually lasts less than a year. The most important aspect of the disease is acute beryllium pheumonitis. This condition may be fatal. Acute disease arises largely out of short-term, accidental over-exposure. Chronic beryllium disease is marked by progressive pulmonary disease and cardiac complications. The prognosis in chronic disease is usually unfavorable.		
The threshold limit value for human exposure to beryllium compounds on an 8-hour time-weighted average is:	0.002 mg/m^3 (air)	American Conference of Governmental Industrial Hygienists (1975)
Cadmium:		
Estimated average daily intake of Cd in humans: Intestinal absorption is low, approximately 3 - 8%. Cadmium is concentrated in the liver and kidneys which contain approximately 50 - 75% of the body burden.	20 - 50 mg/day	Fleischer et al. (1974)

	Concentration	Reference
Study indicates cadmium is not retained in any significant quantity in human body tissue with the major portion being excreted. Absorption of cadmium through the intestinal tract appears to be relatively limited. Renal damage in humans is likely to occur at cadmium concentrations in the outer cortex of the kidney of:	200 ppm	Friberg et al. (1971)
Chronic Cd emphysema may appear after long periods of exposure to levels of:	3 - 15 mg/m^3 (air)	
In fatal cases of acute Cd poisoning, significant pathological changes have been seen in the kidneys. Transient proteinuria has been detected in individuals with non-lethal cadmium exposure. Cadmium is not known to be concentrated in bone tissue. Anemia has been observed in workers exposed to cadmium oxide dust. The evidence that cadmium may act as a carsinogen in man is not yet conclusive.		
Pulmonary emphysema is one of the primary symptoms of chronic cadmium poisoning due to long-term inhalation of Cd fumes, cadmium oxide dust, or cadmium salt. Kidney damage is also considered to be a classic syndrome of chronic poisoning.		Bonnell (1965)
Estimated dose of cadmium causing appearance of toxicity symptoms in humans: Symptoms: Acute nausea and vomiting which may be followed by severe gastroenteritis.	15 - 30 mgms	Gleason (1969)
There may be an increased incidence of renal stones occurring in individuals who have had long-term exposure to cadmium dust.		Ahlmark (1961)
In humans, toxic levels of cadmium by inhalation vary from:	1 - 30 mg/m^3 (air)	Browning (1961)
A positive association may be found between cadmium content of air and mortality ratios associated with heart disease.		Carroll (1966)
Study implicated high levels of cadmium in the kidney as a possible factor of hypertensive disease in humans.		Schroeder (1965)
Cadmium in foods may be capable of producing toxicity symptoms in man at concentrations of:	15 ppm	Underwood (1962)
Acute cadmium response syndrome is characterized by severe nausea, salivation, vomiting, diarrhea, abdominal pains, and myalgia. Liver and/or kidney damage may follow or accompany the development of acute signs. Involvement of the respiratory system may also accompany acute signs. Serious symptoms have appeared with intake of:	10 mgms	Arena (1963)

	Concentration	Reference
Chronic effects of inhaled cadmium include total or partial loss of smell, cough, labored breathing, weight loss, and yellow staining of the teeth.		
Chromium:		
Chromium appears to accumulate in the lungs with increasing human age. It is quite insoluble and appears not to interchange with the rest of chromium body stores. The insoluble compounds appear to be primarily chromium chlorides.		Baetjer (1959)
Trivalent chromium complexes appear to be an essential factor in the control of glucose metabolism. Abnormal glucose tolerances have occurred where a deficiency in trivalent chromium exists.		Schwartz & Mertz (1959)
Trivalent chromium supplementation may improve to glucose tolerance of adults with the response of tolerance improvement indicating a possible marginal deficiency.		Doisey et al. (1968)
In the industrial environment, chronic chromium over-exposure appears usually as a general inflamation of the respiratory system with possible perforation or ulceration of the nasal septum.		Smith (1972)
Copper:		
Daily adult copper requirement: not considered a health hazard except in very large doses.	1 mg	Soukup (1972)
Lethal dose of copper for humans: Symptoms of copper toxicity from single high exposure are usually gastric in nature.	18,000 mg/kg body wt.	International Technical Information Institute (1976)
Maximum T.L.V. of copper fumes in in the work environment: (8-hour time-weighted average)	1 mg/m^3	American Conference of Governmental Industrial Hygienists (1975)
Wilson's disease is the only significant copper toxicity in man. It is an inherited autosomal recessive trait where even normal copper intake accumulates in the vital organs to toxic concentrations.		Scheinberg (1969)
Lead:		
The largest tolerated amount of lead in drinking water for humans appears to be reported in a range of:	0.35 - 2.0 ppm	Cantarow & Trumper (1944)
Under average conditions, lead is taken in at approximately daily rates of 300 micrograms from air. About 10% of injested lead is absorbed and 30 - 50% of inhaled lead. The human threshold for lead intake on a daily basis is approximately:	600 μg/day	Lagerwerff (1972)
Long duration intake of soluble lead compounds by humans may cause adverse symptoms at a level of:	1000 μg/day	Kehoe (1966)

	Concentration	Reference
Under urban conditions, it appears that an appreciable portion of the total human body burden of lead is contributed by inhalation. It is not yet possible to evaluate the significance of small increases in the total body burden of lead from atmospheric sources, but the evidence from industrial workers has not shown any harmful effect.		Kanzantis (1973)
Mercury:		
The most common form of mercury found in the environment and that which is most toxic to man is methyl mercury. Studies indicate that intestinal absorption is between 90 and 95%.		Grant (1971)
It has been shown that methyl mercury has the ability to penetrate the placental barrier and produce fetal damage at levels which have not produced symptoms in the mother.		
The concentration of mercury expected in the diet from natural background levels and environmental contamination is:	0.02 - 0.05 ppm	
The various hazardous concentrations previously reported in the literature for mercury compounds are as follows:		Grant (1971)
possible chromosome damage:	0.02 ppm	
possible fetal damage:	0.40 ppm	
symptoms of toxicity:	0.4 - 1.0 ppm	
Mercury access to the body is gained mainly through the respiratory tract but absorption also takes place through the skin or by ingestion. Mercury inhibits some enzymes, produces potassium ion loss, blocks glucose uptake by erythrocytes and muscle, causes lesions of the central nervous system and influences bioelectric phenomenon by altering transmembrane potentials and by blocking nerve conduction.		Neville (1967)
Mercury may enter the body by inhalation, ingestion, or through the skin. Symptoms of toxicity fall into two classes. These are one with stomatitis, colitis, and nephritis predominating, and the other with tremor, and neurological symptoms.		Neal (1938)
One-half gram of mercuric chloride can be a lethal dose in humans causing shock, ulceration of the gastrointestinal tract, and destruction of the tubular epithelium of the kidney.		Kanzantis (1965)
Most frequent route of administration of methyl mercury is ingestion of protein-bound methyl mercury in food items. The earliest symptoms include fatigue, headache, and reduction in the powers of concentration and memory. A period of up to seven months may be required for appearance of nervous disorders.		Whitehead (1965)

	Concentration	Reference
A concentration of 0.2 ppm in whole blood of methyl mercury is considered the minimum level for neurotoxic exposures in humans. There is some uncertainty as to what constitutes lethal concentrations of methyl mercury in man.		Hammond (1971)
At air concentrations of 60 $\mu g/m^3$ of mercury vapor, the total amount appears to be retained in the lungs. Studies indicate almost total absorption of mercury vapor into the lungs.		Shepherd (1941)
Acute mercury intoxication has resulted in humans from inhalation of mercury vapor at aerial concentrations of:	1200-8500 $\mu g/m^3$	Stokinger (1963)
In the industrial environment, workers have been exposed to inorganic mercury compounds for a period of more than two years with no evidence of mercury intoxication at air concentratons of:	80 - 400 $\mu g/m^3$	Kleinfeld (1961)
Molybdenum:		
There appears to be an interest in the role of molybdenum in human nutrition since studies in New Zealand and England show that children born and reared in high soil molybdenum areas have better teeth than do children in other areas of the countries.		Kubota & Allaway (1972)
Nickel:		
Nickel appears to be poorly absorbed from the ordinary human diet. The fecal excretion of nickel appears to be quite high as opposed to urinary excretion which indicates nickel is poorly absorbed in the gastrointestinal tract.		Horak & Sunderman (1973)
The concern of the effect of atmospheric nickel levels on the health of humans is based on evidence that certain nickel compounds are known to be carcinogenic to man and animals. The nickel levels required to produce observable effects in humans are considerably greater than those found in ambient air. The primary damage of nickel to humans is found in the industrial environment. The most toxic of all nickel compounds used in industry is nickel carbonyl. The threshold limit value of exposure in humans for nickel carbonyl is 0.0001 ppm, making it the most toxic gas on the entire list of substances for which TLV's have been established.		Smith (1972)
Selenium:		
It has been stated that the maximum amount of selenium in the total diet that a human can consume without selenium intoxication appears to be approximately:	3 ppm	Taylor (1952)

	Concentration	Reference
In a literature review concerning selenium in human nutrition, no definite conclusions have been reached. Symptoms comparable to those of selenized domestic animals are essentially lacking. Cases of arthritis have been associated with selenium in the diet. There is some suspicion that other features such as discoloration of skin, bad teeth, dermatitis, and gastrointestinal disorders may be aggrevated by the intake of small amounts of selenium.		Thacker (1961)
From a study by Lemley, human cases of selenium poisoning are more likely to occur from the use of selenium in industry than from the consumption of foods in the areas of seleniferous soils in the U.S.		Moxon (1958)
Selenium concentration considered dangerous to humans are:		
Food levels:	5.0 ppm	
Milk or water levels:	0.5 ppm	
In seleniferous areas of North America, disease conditions in man definitely attributable to selenium poisoning have yet to be demonstrated. There is no direct evidence of humans being affected by high seleniferous soils.		Underwood (1962)
Vanadium:		
Persistent cough has been observed in humans for periods up to eight weeks after exposure to vanadium pentoxide at air concentrations of:	1000 $\mu g/m^3$	Zenz (1967)
A number of workers were exposed to vanadium pentoxide at concentrations ranging from 18-925 $\mu g/m^3$ of air. Results showed that serum cholesterol levels were reduced approximately 10% below that of normal levels.		Lewis (1959)
In a study in England, it was found that the mortality from lung cancer appears to correlate significantly with the concentration of vanadium and particulates in the air. The concentrations of vanadium showed a strong association with the incidence of bronchitis in males. Vanadium and beryllium were found to be associated with the incidence of pneumonia.		Stocks (1960)
The lethal dose of vanadium through inhalation by man appears to be in a range of:	60,000-120,000 $\mu g/m^3$	Stokinger (1963)
Symptoms of vanadium poisoning observed in occupationally exposed groups include: paroxysmal cough, irritation of the throat, eyes, and nose, anorexia, tremors, hysteria, melancholia, and anemia accompanied by reduction in hemoglobin and the number of erythrocytes.		Athanasiadis (1969)

Zinc:	Concentration	Reference
In a reported study, increasing concentrations of soil-applied zinc did not significantly increase the element level in plant seeds. Since seed and fruits are major sources of plant material in human diets, it may be that very substantial increases in the level of available zinc in soils would have only slight effects upon the level of zinc in human diets.		Allaway (1968)
Zinc chloride has a TLV of: Toxicity symptoms: conjunctivitis paratis, popular dermititis and ulceration of the fingers and hands.	1 mg/m^3 air	International Technical Information Institute (1976)
Toxicity of zinc chloride from inhalation shows the following symptoms: irritation of the nose and throat, headache, hoarseness, cough, chest pain, fever, nausea and vomiting, shortness of breath, and asthma along with pulmonary edema.		
Zinc oxide has a TLV of: This substance is the chief cause of metal fume fever.	5 mg/m^3 air	
Symptoms: hacking cough, moderate substernal pain, headache, nausea, vomiting, metallic taste, chilling and fever, pain in muscles and joints, marked thirst, and occasionally pneumonia.		
The ingestion of toxic amounts of zinc in food by humans produces an acute transistory illness within a few minutes after ingestion. Symptoms include: dizziness, tightness of throat, emesis, colic, and diarrhea.		Vallee (1959)
The problem of metal fume fever occupies the most prominent role among the possible toxic effects of zinc for humans.		
Fluoride:		
In man, a steady intake of 0.1 to 0.15 mg/kg body weight per day in drinking water has occasionally shown mottling of the enamel of the teeth.		Pierce (1939)
The oral lethal dose of fluorides in their soluble form for humans is given in a range of:	5 - 10 grams	Smith & Hodge (1965)
Daily fluoride intake in community water supplies which has produced a disfiguring malformation of the enamel surfaces of teeth is given at:	2 - 8 ppm	
Man inhaling ambient air containing less than 0.05 $\mu g/m^3$ and retaining all of it would absorb negligible amounts of fluorides.		Hodge & Smith (1972)
In children, the mottling of teeth has occurred on regular drinking water intakes of fluoride at concentrations of:	2 - 5 ppm	Maynard & Loosli (1969)

	Concentration	Reference
Fluoride concentrations in the domestic water supply which has been established as beneficial in preventing dental caries or tooth decay in humans is:	1 ppm	Mitchell & Edman (1945)
Fluoride intake in the drinking water of humans over a period of approximately ten years has caused no significant histological changes in the bone structure at concentrations of:	0.1 - 4.0 ppm	Zipkin et al. (1958)
Fluorine does not appear to be a dietary essential. The only value to the body appears to be the limited promotion of resistance to dental caries.		Maurer & Day (1957)
Sulfur:		
Eighty percent of urban atmospheric sulfate has been found to be associated with particles below 2 µm in diameter. The small sizes are easily respirable and can penetrate deeply into the lung surfaces.		Hagman et al. (1967)
Sulfur dioxide is a mild respiratory irritant, one of the basic effects is to produce reflex and/or direct broncho-constriction.		Hausknecht (1974)
Decreases in respiratory air flow rates and tidal volume and increases in airway resistance have been observed after 10-minute exposure to sulfates at levels of:	0.35 mg/m^3	Sim & Pattle (1957)
The respiratory irritant effect of sulfur dioxide is enhanced by water aerosols and particle sizes of less than 1 µm.		Snell & Luchsinger (1969)
The average odor threshold of sulfur dioxide in humans at one second exposure time is reported to be:	0.50 ppm	Dubrovakaya (1957)
Respiration and pulse rates in humans have been observed to increase after 10-minute exposures to sulfur dioxide at a concentration of:	1.0 ppm	Amdur and Melvin (1953)
The threshold for inducing measurable broncho-constriction in healthy people from sulfur dioxide for exposure periods of 1 - 5 minutes has been established at a concentration of:	1.6 ppm	Tomono (1961)

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DETERMINATION OF PARTICULATE EMISSION FACTOR FROM LIGNITE MINING OPERATIONS

DETERMINATION OF PARTICULATE EMISSION FACTOR FROM LIGNITE MINING OPERATIONS

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PREPARED FOR

THE BUREAU OF LAND MANAGEMENT
DEPARTMENT OF THE INTERIOR

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PREFACE

This report is the result of a field study conducted during the months of July, August, and September of 1976, in partial fulfillment of BLM Contract Number YA-512-CT6-183.

The purpose of this study was to determine the total particulate emission rates resulting from open pit lignite coal mining operations in Western North Dakota. To establish the emission rates, air sampling sites were placed around two lignite coal mines to monitor the effects of total mining operations on the surrounding air quality. The data collected was subsequently reduced using two separate analytical approaches to yield a total particulate emission factor for strip mining operations.

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INTRODUCTION

As fuel resources such as natural gas and petroleum become less available and more costly, coal will receive increasing emphasis as a primary energy source. The use of extensive Western North Dakota lignite coal deposits may provide a significant portion of the central and mid-western United States energy requirements for the foreseeable future.

Future energy requirements and the accessibility of large quantities of lignite coal reserves have given rise to a need for formulation of a plan for the orderly and environmentally sound development of North Dakota's potential energy resources. This need for a comprehensive energy development plan, has in part, provided a basis for the drafting of a Regional Environmental Impact Statement for energy development in a seven-county area of Western North Dakota. The contents of this report constitute one element of the Regional Environmental Impact Statement.

The element addressed in this research effort deals primarily with the effect of strip mining operations on the air quality in Western North Dakota. To adequately address a comprehensive assessment of environmental impacts on air quality, the total particulate emissions resulting from open pit strip mining operations must be included with all other emission sources which directly affect the existing air quality. Research by the authors indicates that this report constitutes the first efforts to assess the particulate emission contribution of open pit strip mining activities to the air quality in North Dakota.

OBJECTIVES

The major objective of this study is to establish an emission factor for airborne particulate matter resulting from open pit strip mining activities. This factor will be used as a basis for determining the environmental impact on air quality of proposed additional strip mining operations in a seven-county energy development area of Western North Dakota.

METHODS AND INSTRUMENTATION

Description of the Study Areas

Two operational open pit coal mines which were considered representative of the mining activities in Western North Dakota were selected for this study. These study mines are designated as Mine A located near Stanton, North Dakota and Mine B located near Beulah, North Dakota. The time periods for this study were from July 6, 1976 to August 6, 1976 at Mine A and from August 11, 1976 to September 11, 1976 at Mine B.

Four sampling sites were selected in and around Mine A. The selection of these sites was based on prevailing wind climatology of the area relative to the major mining activity and accessibility to 110 AC power. The four sites selected were at the following locations:

Site A-1------------------------located south of the major mining activity.

Site A-2------------------------located southeast of the major mining activity off mine property.

Site A-3------------------------located north of the major mining activity off mine property.

Site A-4------------------------located west of the major mining activity off the mine property.

For a description of the mine, the location of the sites relative to each other, and the area of major mining activity see Figure A-1 in Appendix A. The major mining activity during this time period, the location of this activity and coal production information are supplied in Appendix A.

Four sites were selected in and around Mine B according to the criteria described above in the Mine A description. The four sites selected are outlined below:

Site B-1------------------------*located at the north end, but within the major mining activites.

*NOTE: This location is surrounded by the haul roads used in transporting the coal from the pits to the tipple.

Site B-2------------------------on the mine site; located to the southeast of the major mining activities.

Site B-3------------------------on the mine site; located to the southeast of Site #2.

Site B-4------------------------off mine property located to the west-southwest of the mine.

Figure A-8 in Appendix A shows the mine, the site locations and the area of major mining activity. A description of the major mining activites and coal production levels are supplied in Appendix A, Mining Activites.

Instrumentation

The instrumentation for this study was selected to provide information regarding the levels of emission of particulate matter in both the settled and suspended particle size ranges. Also a surface meteorological station was established at one of the sites during the study time frame to determine wind speed and wind direction with secondary parameters being temperature and relative humidity. The study parameters and instrumentation used are as follows:

1. Total Suspended Particulate (TSP) Matter

A high volume sampler was used to collect the suspended particulate matter (10). This instrument utilizes an industrial-type "vacuum motor" which pulls large quantities of air (40 to 60 CFM) through a fiberglass filter. The filter is designed to separate particles from the atmosphere with an average particle size of 10μ (characteristic of a non-urban environment; larger suspended particulates may be found in urban environments) (6). A high volume sampler was placed at each of the four sites at the two mines and was operated six days a week (Monday through Saturday) for the one-month study period at each mine.

2. Settled Particulate Matter (Dustfall)

Standard dustfall jars were used to collect settled particulate matter. (11) Dustfall is the usual index of particles in the size range greater than 10μ and it is usually reported in short tons per square mile per month. The values utilized throughout this report are in short tons per square mile per month. This is arrived at by extrapolation from a jar a few inches in diameter to a square mile (6) A dustfall jar was placed at each of the four sites at the two mines and exposed for a month.

3. Meteorological Data

A surface meteorological station (SMS) was installed at each mine during the study period. It collected wind speed and direction, temperature and relative humidity continuously. The SMS was placed at sampling site A-3, and sampling site B-4. During the study period mechanical breakdown of the

SMS was experienced. For these time periods when missing data was noted, the meteorological data was supplemented with Bismarck weather data (9) and wind roses from a site located near Dunn Center, North Dakota, operated by the Climatic Data Laboratory, NDSU. (7) See Appendix B entitled Meteorological Data.

Data Flow and Quality Assurance Procedures

Data gathering operations were monitored by a fieldman who was present during the normal working hours of the day. His sole function was to collect samples in a timely fashion and implement maintenance and calibration on equipment during established timetables. After each 24-hour high volume sampling run, the fieldman collected the filters from the four sites. The filters were then placed in envelopes and mailed to the North Dakota State Department of Health (NDSDH) Laboratories for weighing and analysis according to Standard NDSDH Air Pollution Control Program procedures. The samplers were then supplied with clean filters for the next day's operation and the above procedures were repeated.

The dustfall sampling buckets from four sites were collected at the end of the study period at each mine. These samples were then transported to the NDSDH Laboratory for analysis as per standard procedures mentioned above. The meteorological data was recorded on strip charts. These were collected by the field operator and sent to the NDSDH, Division of Environmental Engineering for digitization reduction into logbooks, which are on file with the Division. The TSP information was keypunched on computer cards and sent to the Central Data Processing (CDP) Center for statistical analysis and summarization. Figure 1 summarizes the data flow from field collection phase of the project to NDSDH "in-house" files. All TSP and Dustfall Data collected can be seen in Appendix C entitled Air Quality Data.

Quality Assurance

A strict quality assurance procedure was followed throughout this project. This procedure included maintenance schedules, calibration schedules, and quality checks throughout the data flow procedures. All equipment was initially calibrated before field installation. In addition, the high volume samplers were calibrated once per week throughout the study period. The meteorological instruments were also calibrated periodically and checked against existing area meteorological information sources. Maintenance was performed on all equipment prior to field installation and periodically as needed during the study periods. This included replacing carbon brushes in the high volume samplers every two weeks throughout the study periods. The data flow procedures were carefully observed to assure all analysis procedures followed established NDSDH guidelines. All data is stored in several forms to provide adequate back-up for data recovery and future reference. This includes strip charts, digitized forms in logbooks, punched computer cards and hard copy computer printouts.

DATA PRESENTATION AND ANALYSIS PROCEDURES

In the determination of a gross emission rate of particulate

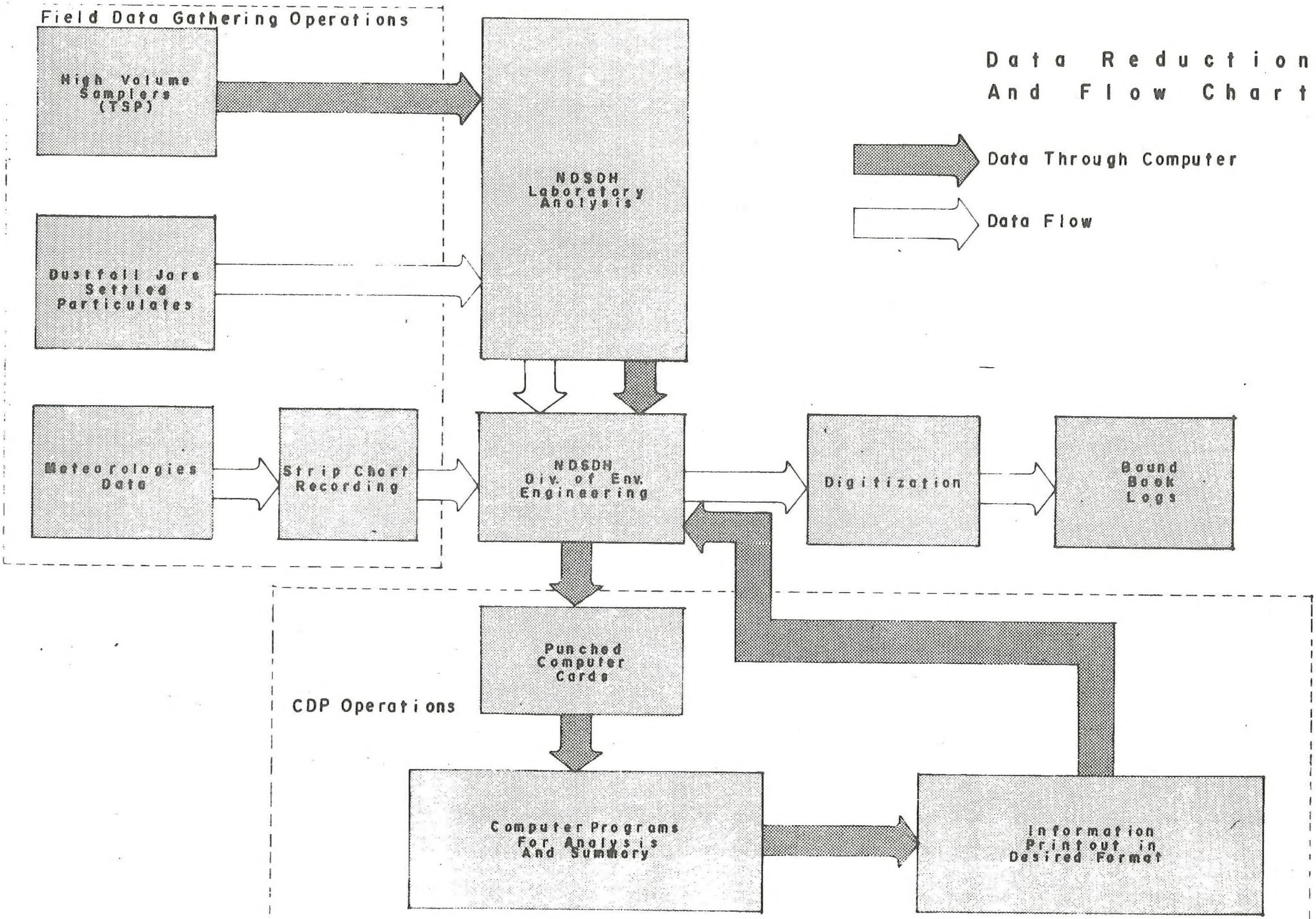
Field Data Gathering Operations
Data Reduction And Flow Chart
Data Through Computer
Data Flow
High Volume Samplers (TSP)
NDSDH Laboratory Analysis
Dustfall Jars Settled Particulates
Meteorologies Data
Strip Chart Recording
NDSDH Div. of Env. Engineering
Digitization
Bound Book Logs
Punched Computer Cards
CDP Operations
Computer Programs For Analysis And Summary
Information Printout in Desired Format

Figure 1

matter from a coal mine, two basic particulate size ranges should be considered, i.e., settled and suspended particulate matter. In this section of the study the field data was analyzed according to that criteria. Therefore, the following discussion includes a narrative and analysis of field data under headings entitled Settled Particulate and Total Suspended Particulate for both mines.

Settled Particulate

Determination of settled particulate produced by mining activities required two major steps. The first step involved determining the percent time a particular sampling site was downwind from a mining activity area. The second step involved a determination of settled particulate resulting from the mining activity under consideration. Both conditions were then analyzed through a back-calculation method and the results are herein summarized.

In determining the influence of mining operations on the sampling sites, an area of mining activity was established for each mine. This included all activities which occurred during the study period. See Appendix A for a detailed description of these activities and locations.

A graphic representation of the sixteen wind directions was then super-imposed over the center of the area of mining activity so that the directions of the two would be congruent, i.e., north on the wind direction graphics would correspond to north on the mining activities map. See Figure 2-A for Mine A and Figure 2-B for Mine B.

The influence of these mining activities on each sampling site was then determined. The percent time (frequency) each sampling site was downwind from the mining activities was calculated. See Figures 3-A through 3-D for Mine A and Figures 4-A through 4-D for Mine B. The wind directional breakout at each site for each mine and the corresponding frequency is described on Table 1. (Note: Direction indicated is the wind direction origin.) The settled particulate collected represented both source contribution and total background concentrations. The source contribution was obtained by multiplying the percent frequency wind influence times the actual measured value. The background concentration was considered to be the difference between the measured value and the source contribution. The background concentration for the site located within the area of mining activities (wind frequency - 100%) was obtained by averaging the background levels previously mentioned from the other three sites. The percent frequency wind influence is found in Table 1. Tables 2 and 3 summarize the source contributions and background level determinations. By using this approach, a value for settled particulate resulting from mining activities was obtained.

The method for relating the measured settled particulate concentrations (reduced to show wind frequency percentage) to the area of mining activity was established. The first step in this procedure was to calculate an average source contribution ($\overline{SC}$) by averaging the adjusted settled concentrations (values

Relationship Between Wind Direction Mining Activities And Site Locations
Mine A
July 6 1976 To August 6 1976

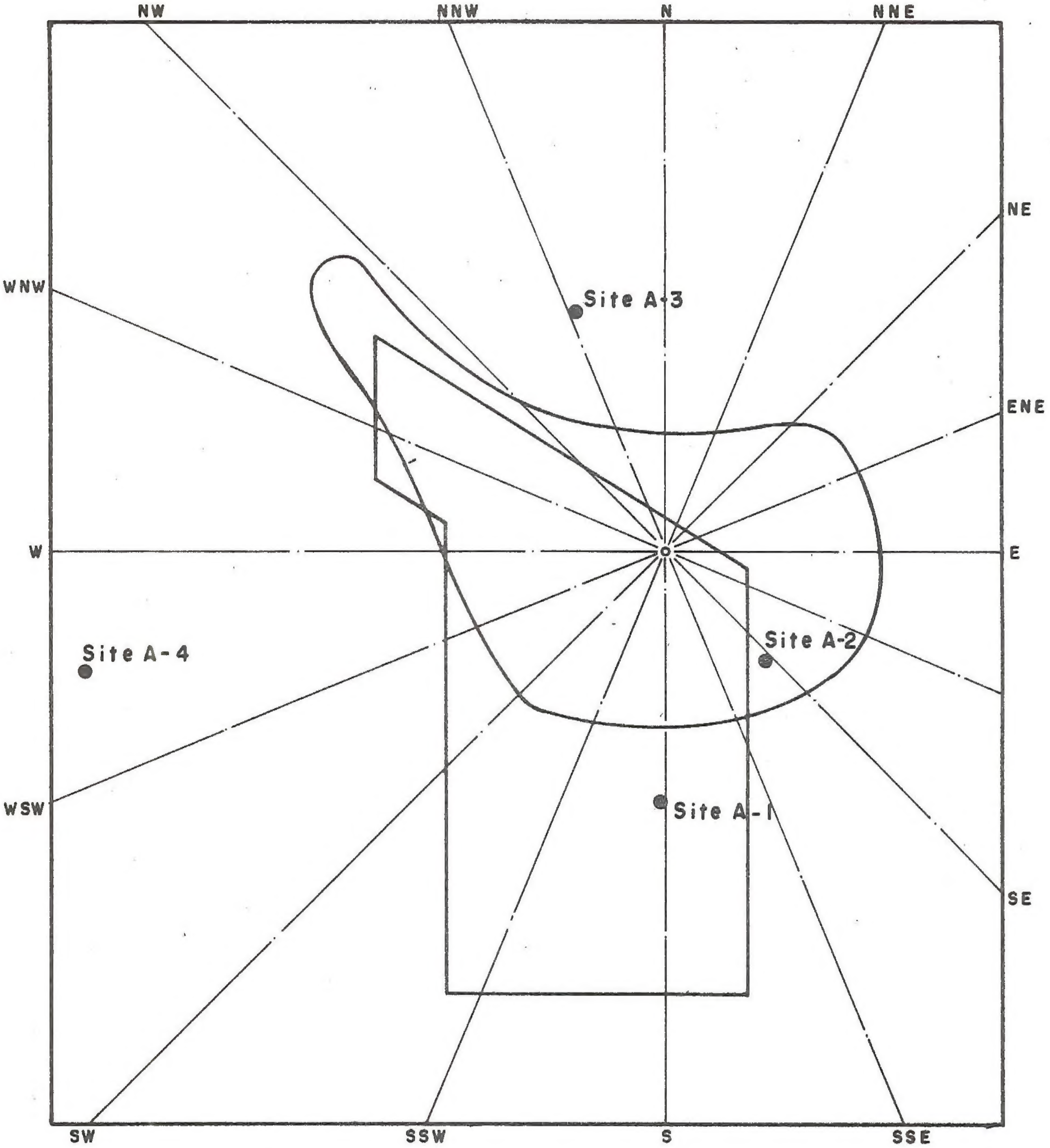

Figure 2-A

Relationship Between Wind Direction Mining Activities And Site Locations
Mine B
August 11 1976 To September 11 1976

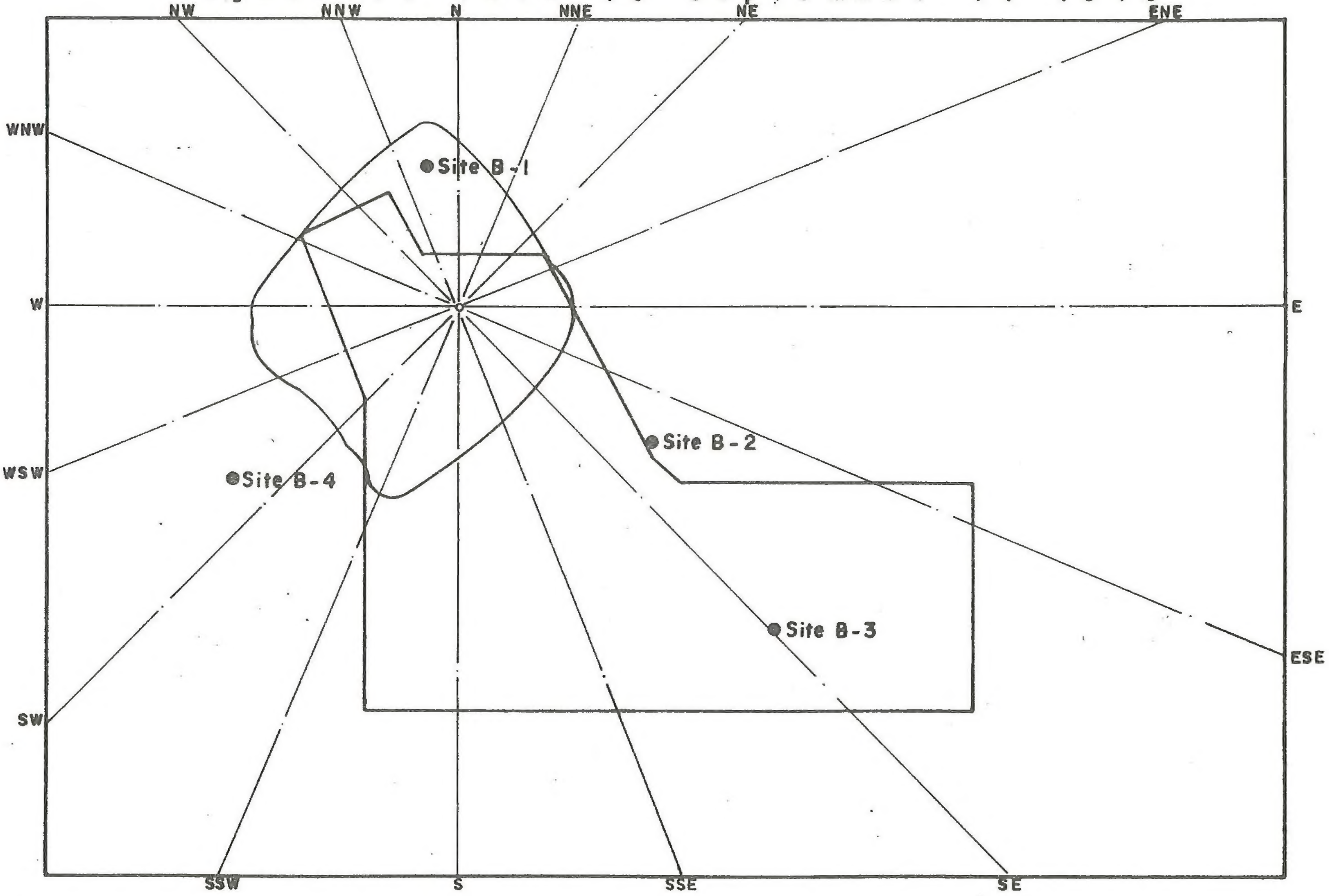

Figure 2-B

Wind Directions Affecting Site With Respect To Mining Activity Mine A

July 6 1976 To August 6 1976

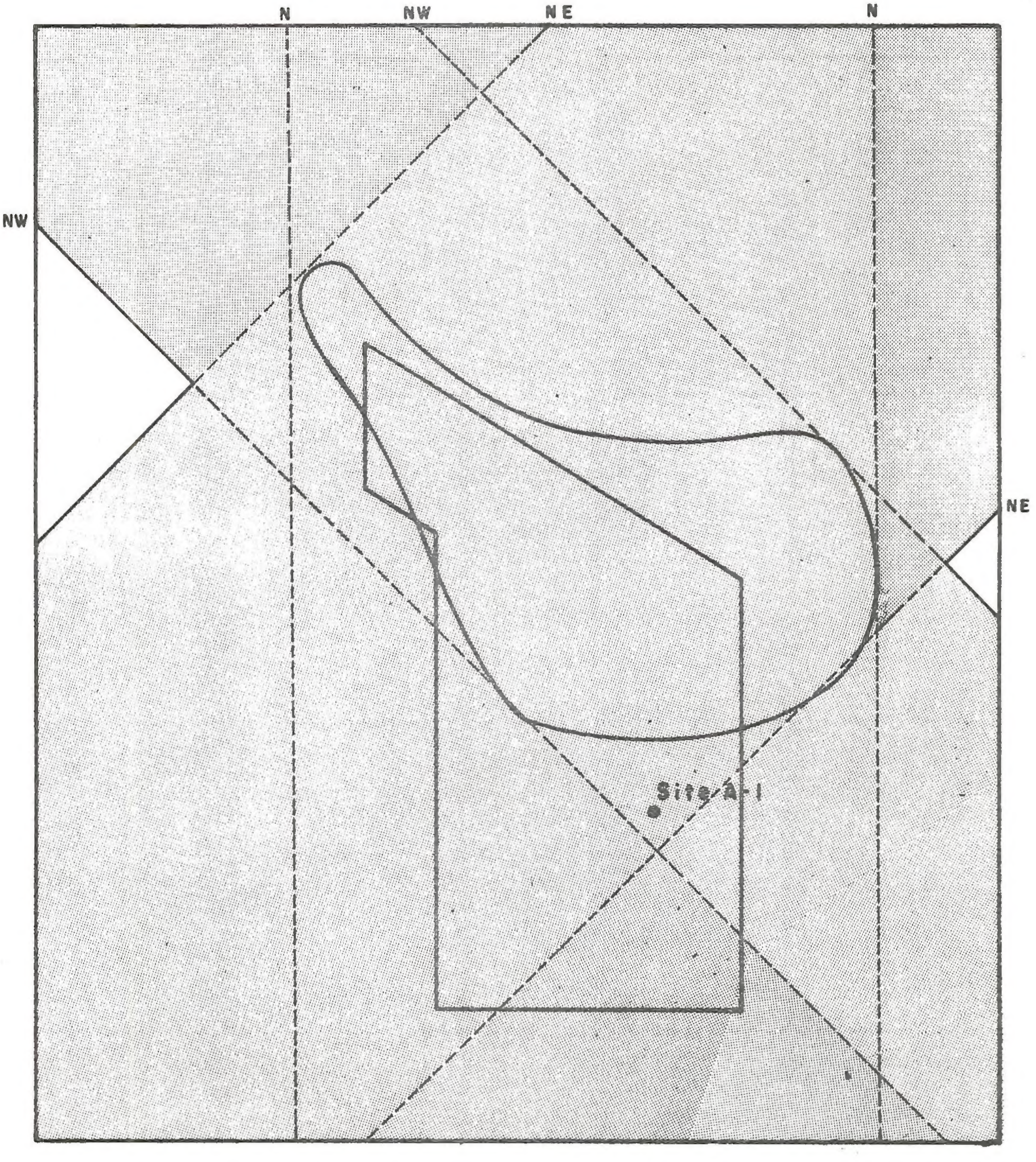

Figure 3-A

Wind Directions Affecting Site With Respect To Mining Activity
Mine A
July 6 1976 To August 6 1976

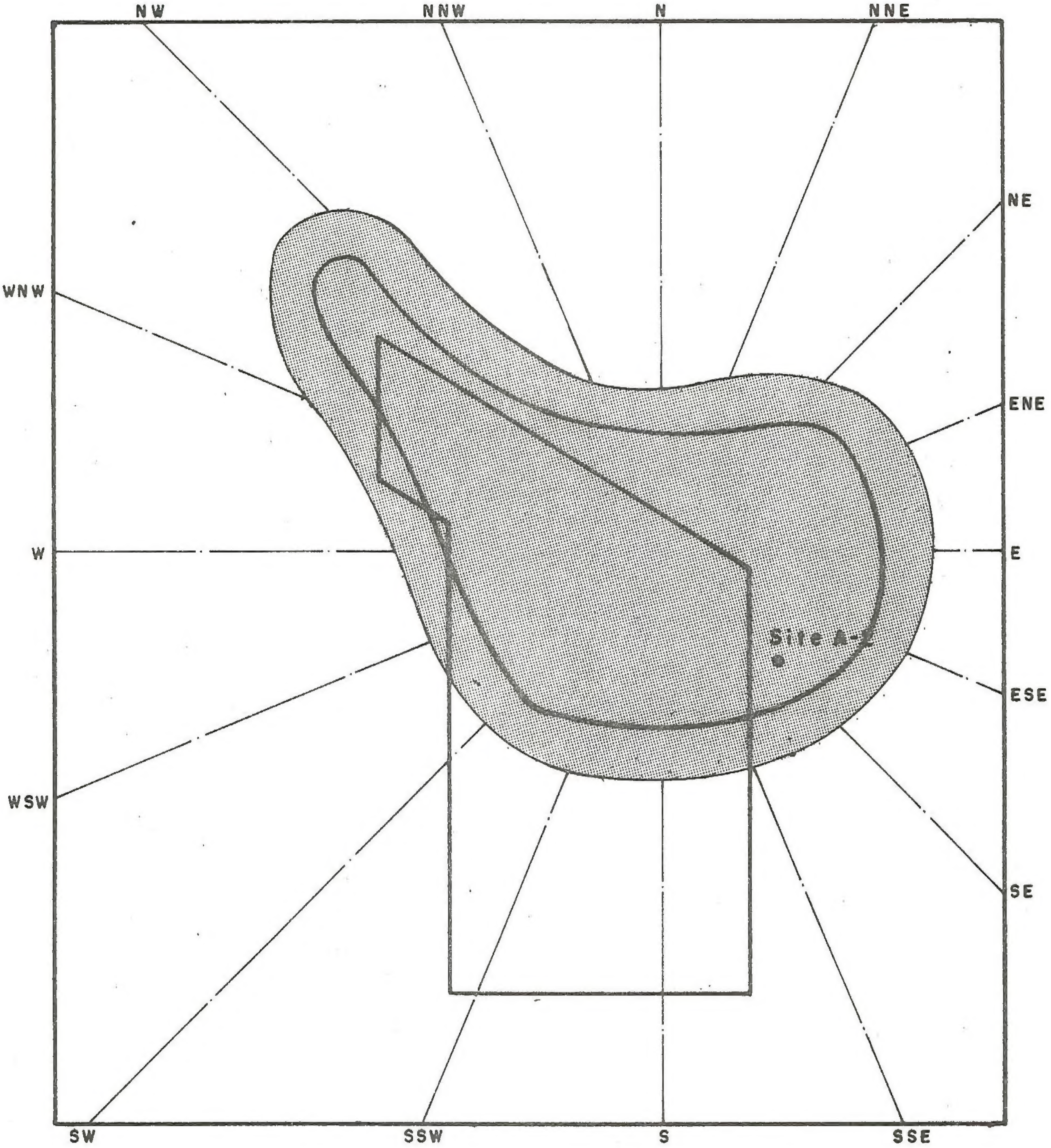

Figure 3-B

Wind Directions Affecting Site With Respect To Mining Activity Mine A July 6 1976 To August 6 1976

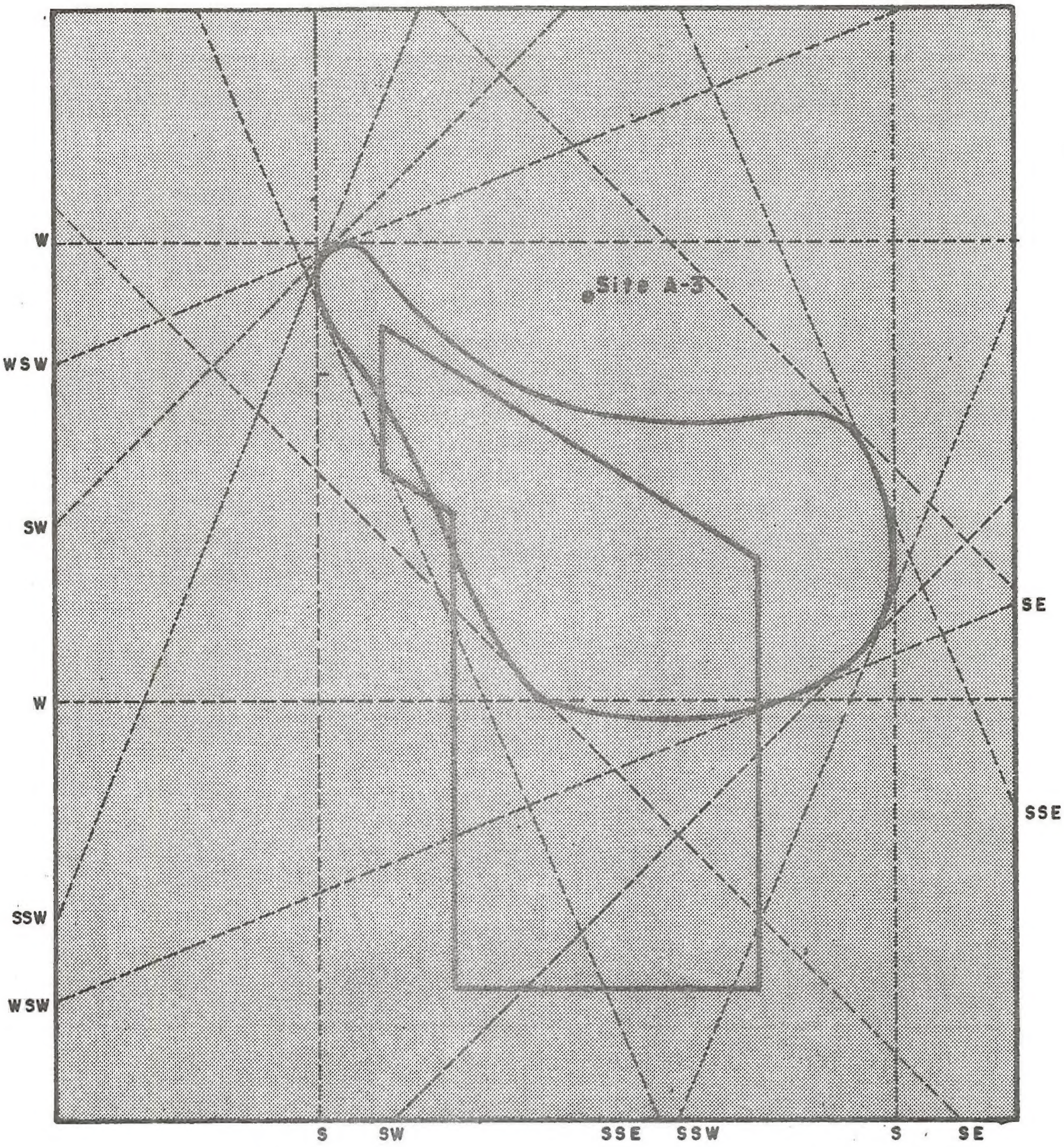

Figure 3 - C

Wind Directions Affecting Site With Respect To Mining Activity
Mine A
July 6 1976 To August 6 1976

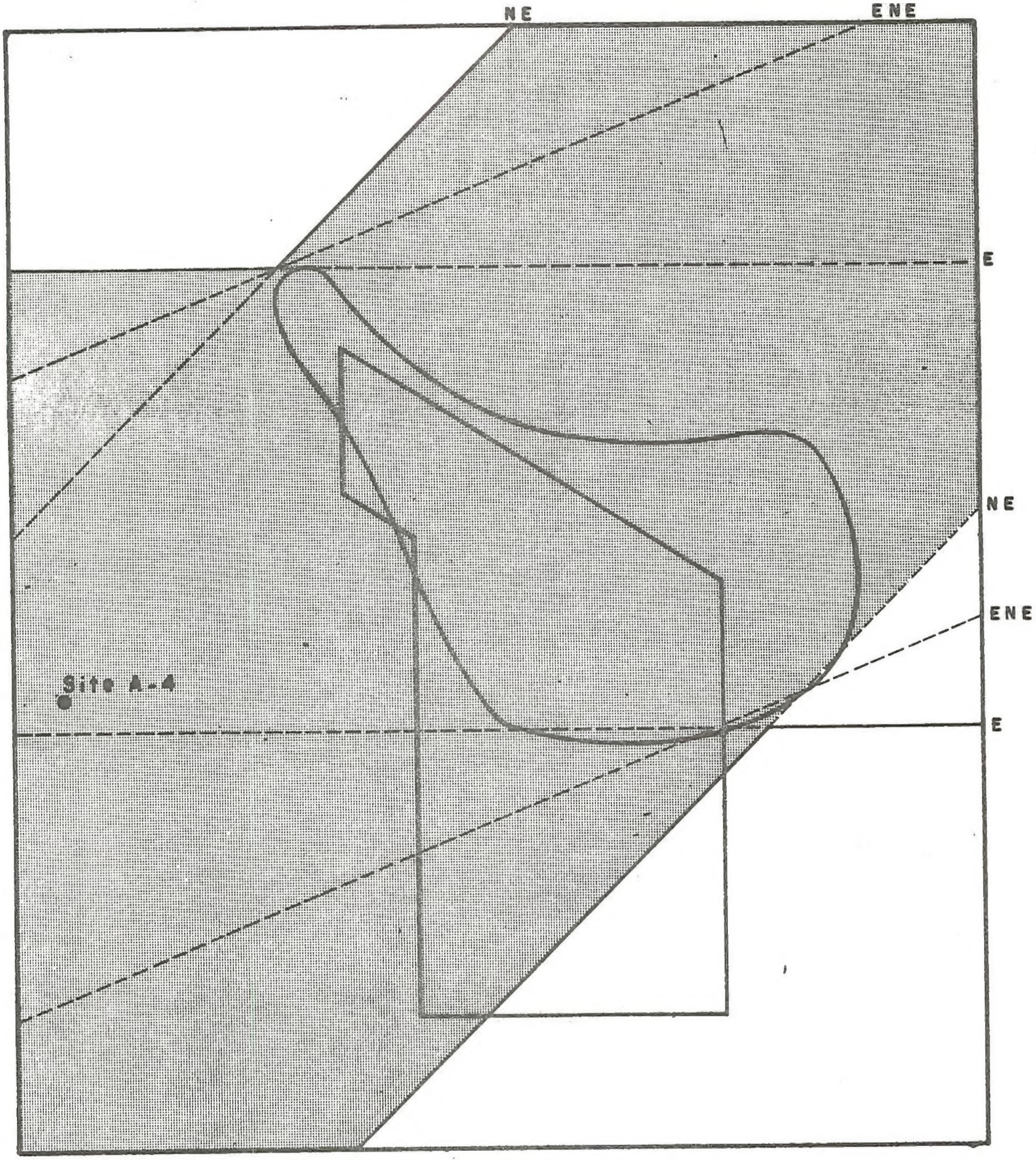

Figure 3-D

Wind Directions Affecting Site
With Respect To Mining Activity
Mine B
August 11 1976 To September 11 1976

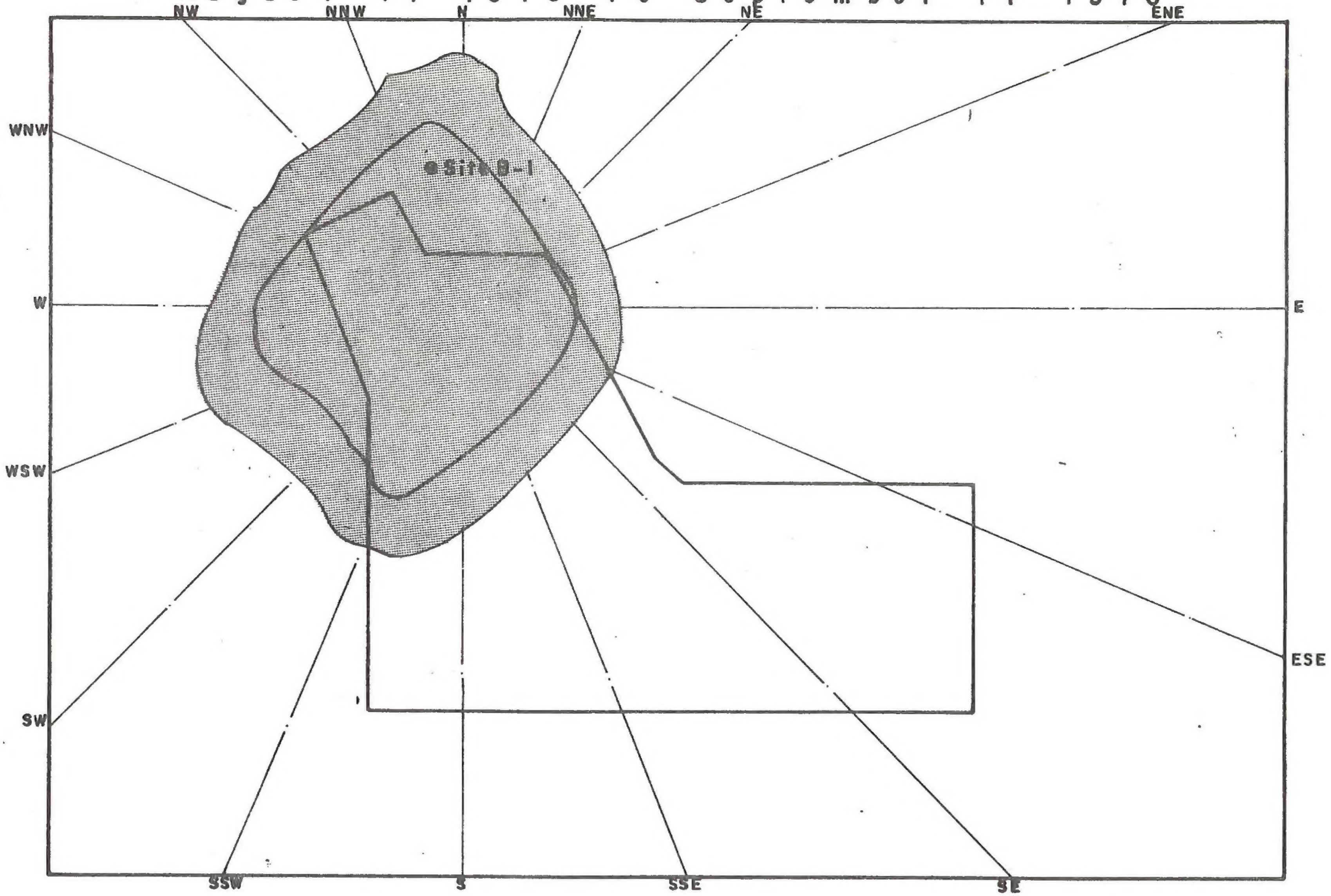

Figure 4-A

Wind Directions Affecting Site
With Respect To Mining Activity
Mine B
August 11 1976 To September 11 1976

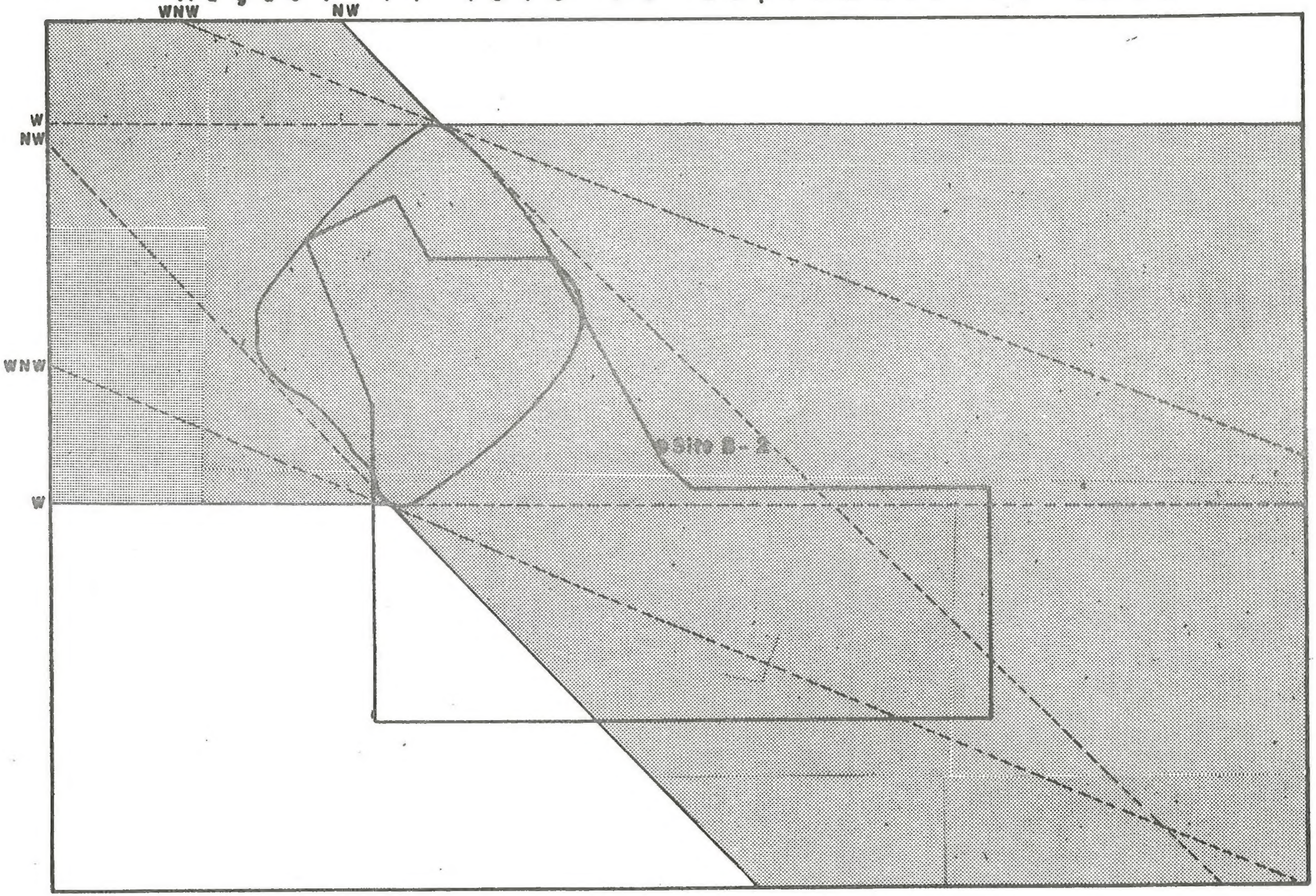

Figure 4-B

Wind Directions Affecting Site
With Respect To Mining Activity
Mine B
August 11 1976 To September 11 1976

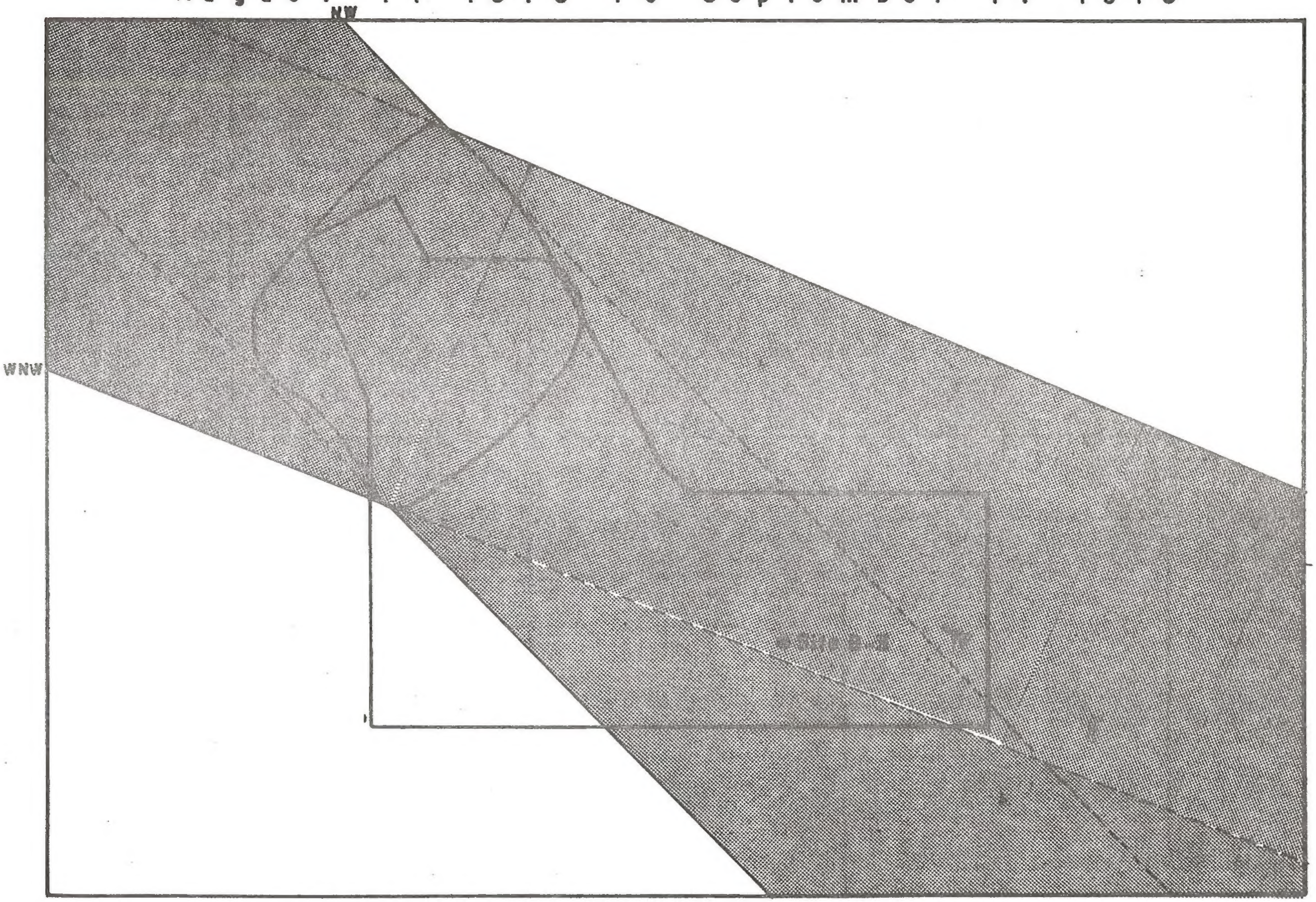

Figure 4-C

Wind Directions Affecting Site
With Respect To Mining Activity
Mine B
August 11 1976 To September 11 1976

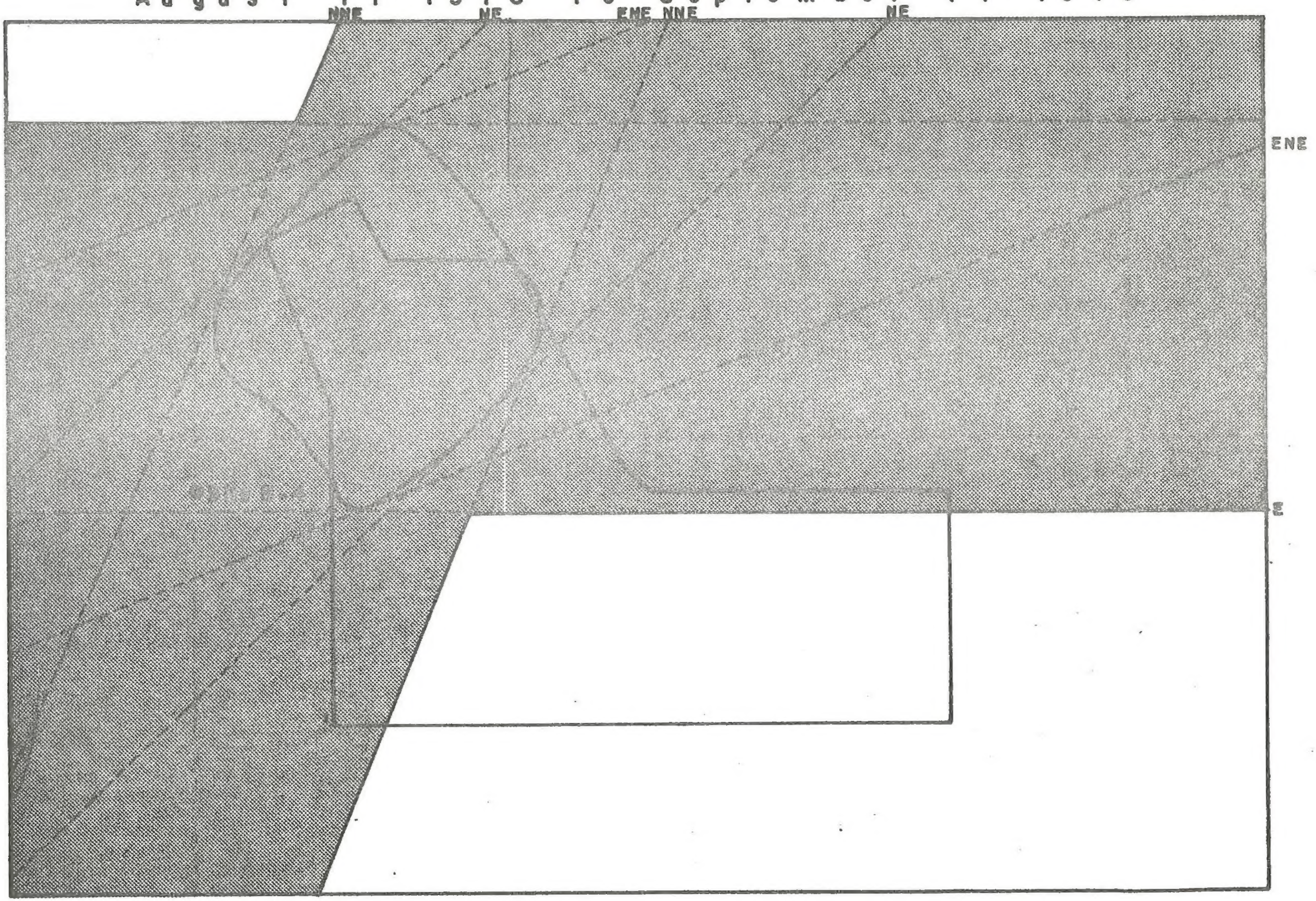

Figure 4-D

TABLE 1: WIND DIRECTIONAL INFLUENCE ON SAMPLING SITES AT MINE A AND MINE B DURING THE STUDY PERIOD

Site Number	Downwind Directional Influence*- Mine A	% Frequency	Site Number	Downward Directional Influence*- Mine B	% Frequency
A-1	NW, MNW, N, NNE	24.86	B-1	all directions	100.**
A-2	all directions	100.**	B-2	NW, WNW, W	27.71
A-3	W, WSW, SW, SSW S, SSE, SE	30.43	B-3	NW, WNW	19.62
A-4	NE, ENE, E	16.40	B-4	NNE, NE, ENE, E	19.47

*Wind Direction Origin

**Site Located Within Designated Activity Area

TABLE 2: SITE SPECIFIC SETTLED PARTICULATE, MINE A JULY 6 TO AUGUST 5, 1976

Sample Site Number	Measured[1] Value	% Frequency[2] Wind Influence	Background[1] Value	Source[1] Contribution
A-1	25.25	24.86	18.97	6.28
A-2	18.97	100.00	14.53[3]	4.44
A-3	27.06	30.43	18.83	8.23
A-4	6.93	16.40	5.79	1.14

[1] Tons/mi^2/month

[2] Data from Table 1

[3] Determined by averaging background levels of sites A-1, A-3, and A-4 because site A-2 was located within mining activity area 100% of the time.

TABLE 3: SITE SPECIFIC SETTLED PARTICULATES, MINE B AUGUST 11 TO SEPTEMBER 11, 1976

Sample Site Number	Measured[1] Value	% Frequency[2] Wind Direction	Background[1] Value	Source[1] Contribution
B-1	9.87	100.00	9.30[3]	0.57
B-2	11.03	27.71	7.97	3.06
B-3	4.40	19.62	3.54	0.86
B-4	20.34	19.47	16.38	3.96

[1] Tons/mi^2/month

[2] Data from Table 1

[3] Determined by averaging background levels of sites B-2, B-3, and B-4 because site B-1 was located within mining activity area 100% of the time.

presented in Table 2 and 3 under column "Source Contributions"). A total source contribution area (SCA) was then determined. This area was described by a circle with a radius equal to the distance from the furthermost receptor (R_4) to the center of the mining activity area. The radial distance was assumed to be the outer limit of settled particulate influence from mining activities. The settled particulate contribution to SCA was then determined by taking $\overline{SC}$ x SCA as described above, and converting the units from tons per square mile per month to grams per month, thus producing total source contribution (TSC). The $\overline{SC}$ was adjusted to reflect contribution to SCA less the R_4 site value. Therefore, by dividing the R_4 value by $\overline{SC}$ and subtracting from unity; multiplying by 100; a percent value, assumed to be the settled particulate concentration within SCA, was obtained. The total emission factor (EF_t) was calculated by converting TSC from grams per month to grams per second using mining activity time period in seconds. A general emission factor (EF) was calculated for a one square mile area by dividing EF_t by the area of the mining activities. This EF can be used to determine the emissions of settled particulates from a mine of any size. The calculations and resulting EF_x for Mines A and B are presented in Table 4.

Suspended Particulate

The determination of suspended particulate emissions from the mining activities was approached in the same manner as the settled particulate procedure previously discussed. Figure 5 shows the locations of the existing TSP sampling sites which were utilized

TABLE 4: Emission Factors For Settled Particulate

Mine A

1. A-1 = 6.28
A-2 = 4.44
A-3 = 8.23
A-4 = 1.14
20.09

$\overline{SC} = \underline{\underline{5.02\ \text{tons/mile}^2\text{/month}}}$

2. R_4 = site A-4 = 3.75 miles (radius)
Therefore SCA = $\pi\ (3.75)^2 = \underline{\underline{44.18\ \text{miles}^2}}$

3. TSC = SCA x $\overline{SC}$
TSC = $(44.18\ \text{miles}^2) \times (5.02\ \text{tons/mi}^2\text{/month}) \times (2000\ \text{lb/ton}) \times (454\ \text{g/lb})$
TSC = $\underline{\underline{2.01 \times 10^8\ \text{g/month}}}$

4. $P\overline{SC} = 1.00 - \frac{1.14}{5.02} \times 100 = \underline{\underline{77\%}}$

5. EF_t = (TSC)/(mining operation time in sec)$(P\overline{SC})$
$EF_t = \frac{2.01 \times 10^8\ \text{g/month}}{(1.32 \times 10^6\ \text{sec/month})(0.77)}$
$EF_t = \underline{\underline{198.12\ \text{g/sec}}}$

6. EF = EF_t/area of mining activity
$EF = \frac{(198.12\ \text{grams/sec})}{(5.0\ \text{miles}^2)}$
$EF = \underline{\underline{39.62\ \text{grams/sec/mile}^2}}$

Mine B

1. B-1 = 0.57
B-2 = 3.06
B-3 = 0.86
B-4 = 3.96
8.45

$\overline{SC} = \underline{\underline{2.11\ \text{tons/mile}^2\text{/month}}}$

2. R_4 = site B-3 = 3.0 miles (radius)
Therefore SCA = $\pi\ (3)^2 = \underline{\underline{28.27\ \text{miles}^2}}$

3. TSC = SCA x $\overline{SC}$
TSC = $(28.27\ \text{mi}^2) \times (2.11\ \text{tons/mi}^2\text{/month}) \times (2000\ \text{lb/ton}) \times (454\ \text{g/lb})$
TSC = $\underline{\underline{5.42 \times 10^7\ \text{g/month}}}$

4. $P\overline{SC} = 1.00 - \frac{0.86}{2.11} \times 100 = \underline{\underline{59\%}}$

5. EF_t = (TSC)/(mining operations time in sec)$(P\overline{SC})$
$EF_t = \frac{5.42 \times 10^7\ \text{g/month}}{(6.62 \times 10^5\ \text{sec/month})(0.59)}$
$EF_t = \underline{\underline{138.77\ \text{g/sec}}}$

6. EF = (EF_t)/(area of mining activity)
$EF = \frac{138.77\ \text{grams/sec}}{1.25\ \text{miles}^2}$
$EF = \underline{\underline{111.02\ \text{grams/sec/mile}^2}}$

SAMPLE SITES USED FOR COMPARISON WITH CALCULATED TSP VALUES

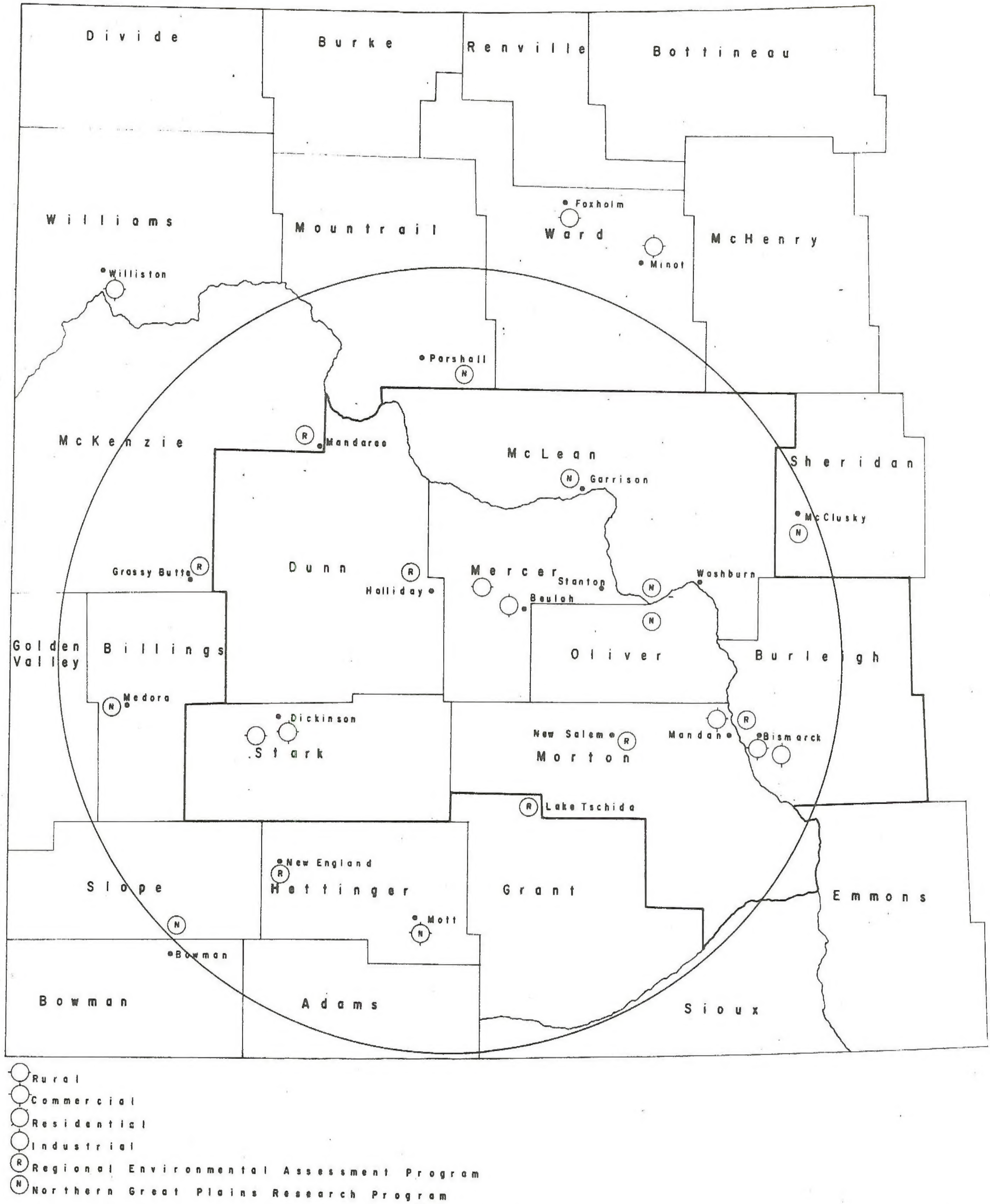

Figure 5

for comparison with calculated background values determined independently by Blackwood and Rusek (2) for the State of North Dakota based on wind erosion equations obtained from Woodruff and Siddoway. (8) The entire North Dakota Air Quality Monitoring Network is described in Appendix D.

The measured TSP values were multiplied by the percent frequency of time a specific site was downwind from the mining activity area. (Data from Table 1 and Figures 3-A-D and 4-A-D.) The result thus derived was considered as the source contribution from the mining activity areas. A summary of these results is found in Tables 5 and 6 for both Mine A and Mine B.

The emission factor for TSP from mining operations was obtained using the source contribution values found on Tables 5 and 6 and back-calculating through Turner's Gaussion dispersion equations for an area source as follows: (1)

$$Q = \frac{\chi(\pi\sigma_y\sigma_z\bar{u})}{e\ [-\frac{1}{2}(\frac{H}{\sigma_z})^2]}$$

Where: Q is the desired emission rate in grams/second

χ is the source contribution in $\mu g/m^3$

π is the constant 3.1417

σ_y is the horizontal dispersion coefficient in meters

TABLE 5: SUSPENDED PARTICULATE CONCENTRATIONS, MINE A

Sample Site Number	Average1/ Measured Value	% Frequency2/ Wind Influence	Background1/	Source1/ Contribution
A-1	34	24.86	25.54	8.45
A-2	97	100.00	30.983/	66.02
A-3	50	30.43	34.79	15.22
A-4	39	16.40	32.60	6.40

1/ $\mu g/m^3$

2/ Data from Table 1

3/ Determined by averaging background levels of sites A-1, A-3, and A-4 because site A-2 was located within mining activity area 100% of the time.

TABLE 6: SUSPENDED PARTICULATE CONCENTRATIONS, MINE B

Sample Site Number	Average[1/] Measured Value	% Frequency[2/] Wind Influence	Background[1/]	Source[1/] Contribution
B-1	191	100.00	63.06[3/]	127.94
B-2	78	27.71	56.39	21.68
B-3	53	19.62	42.60	10.40
B-4	112	19.47	90.19	21.81

[1/] $\mu g/m^3$

[2/] Data from Table 2

[3/] Determined by averaging background levels of sites B-2, B-3, and B-4 because site B-1 was located within mining activity area 100% of the time.

σ_z is the vertical dispersion coefficient in meters

$\bar{u}$ is the average windspeed in meters/second

e is the natural logrithmic constant

H is the effective stack height in meters

Average wind speed and stability class was determined for each mine location specific to each study time period. Table 7 presents a summary of this information and other data used for input in the above equation.

Following the methodology described by Turner (1), the emission rates from the mining operations for each sampling site at each mine was determined and is presented in Table 8. The emission factors (Q) calculated at each sampling site were subsequently averaged to obtain one emission rate value at each mine for TSP.

In any study of this nature, a large number of variables exist which are not readily explainable. This study has attempted to evaluate the influence of mining activities on ambient particulate loading. The emission factors derived in this study are the best available at this point in time and show a correlation with the research efforts of other investigators. (2)(13)

Some of the difficulties with interpretation of data derived from a short-term study are graphically presented in Figure 6. This Figure presents the raw data from sampling site A-1 comparing the

TABLE 7: AVERAGE WIND SPEED DETERMINATION FOR MINE A AND MINE B DURING STUDY PERIODS

Sample Site Number	Wind Speed and Direction	Average Wind Speed		Sample Site Number	Wind Speed and Direction	Average Wind Speed	
		M.P.H.	m/sec			M.P.H.	m/sec
A-1	NW 15.2 NNW 16.5 NE 13.7 NNE 11.6 N 11.5	13.8	6.17	B-1	All directions	16.4	7.33
A-2	All directions	16.1	7.2	B-2	NW 15.4 WNW 18.5 W 14.8	16.2	7.24
A-3	W 13.6 WSW 14.6 S 17.4 SSE 16.5 SW 15.5 SSW 18.0 SE 19.9	16.5	7.38	B-3	NW 15.4 WNW 18.5	17.0	7.6
A-4	NE 11.6 ENE 14.1 E 16.8	14.7	6.57	B-4	NNE 14.2 NE 13.3 ENE 15.6 E 16.4	14.9	6.66

TABLE 8: CALCULATED EMISSION FACTORS FOR TSP

Sample Site Number[1]		Calculated Emission Factor (Q in grams/sec)
A-1		3.48
A-2		1.89
A-3		9.03
A-4		5.24
	AVERAGE	4.91
B-1		33.03
B-2		7.58
B-3		6.09
B-4		8.07
	AVERAGE	13.69

[1] All calculations based on mine activity area of one square mile.

Comparison Of Wind Velocity With Measured TSP Concentration in Sample Sampling Site A-1

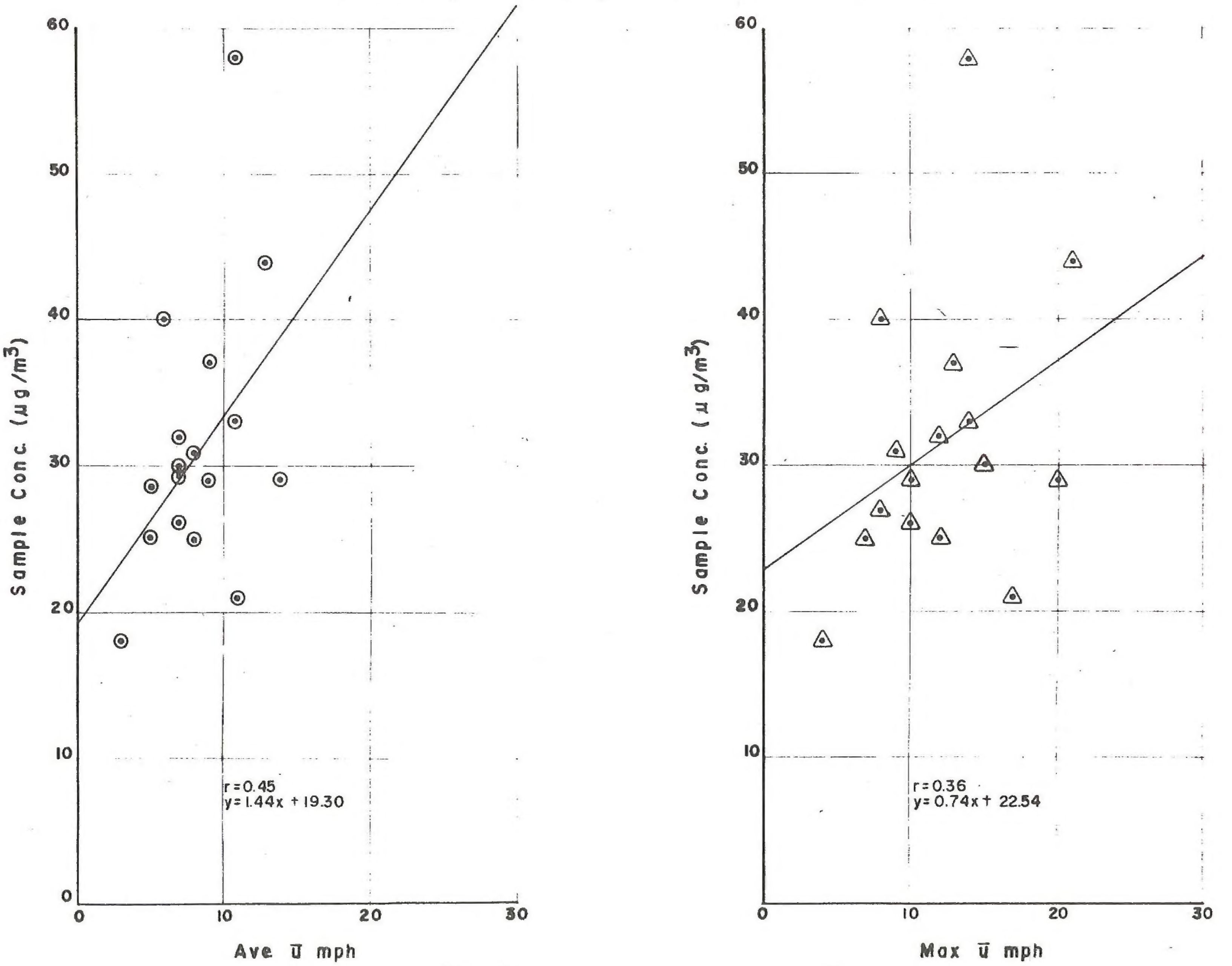

Figure 6

wind velocity with measured suspended particulate concentrations. Although the data can be reduced to a straight line, the data correlation coefficient (r) for this line would not be in the scientific sense, a desirable quantity. This is evident by the range of data points around the reduced line of best fit. A review of Figure 6 points out the need for a more detailed study over a longer period of time to define and reduce the number of variables and to obtain a larger quantity of data for more statistically refined data evaluation.

The values indicated in this report for gross emission factors are those which the North Dakota State Department of Health will be using as interim factors in assessing the air quality impacts of open pit strip mining of lignite coal in North Dakota. A complete listing of all Hi-Volume sampler data and dustfall information utilized in the calculation of the emission factors is given in Appendix C.

CONCLUSION

The total particulate emissions for open pit lignite coal mines in North Dakota were determined to be the algebraic sum of the settled particulate and the suspended particulate average values. Both the settled and suspended particulate emissions were calculated for a one square mile area. The mine size was taken into account by multiplying the total emission factor for each mine by its area of activity. The results are shown on Table 9.

TABLE 9: TOTAL EMISSIONS FROM OPEN PIT STRIP MINES IN WESTERN NORTH DAKOTA

Emission (g/sec/mi^2)

Coal Mine	Settled Particulate	Suspended Particulate	Total	Adjusted for Area[1/]
Mine A	39.62	4.91	44.53	222.65
Mine B	111.02	13.69	124.71	155.89
AVERAGE	75.32	9.30	84.62	

[1/] Mine A = 5.0 mi^2 x Total Emission Factor (g/sec/5.0 mi^2); Mine B = 1.25 mi^2 x Total Emission Factor (g/sec/1.25 mi^2)

The results of the two mines from this short-term study are in reasonable agreement. Mine B has a greater emission rate per square mile, but Mine A is larger and therefore has a greater impact on the air quality with respect to particulate loading of the atmosphere. This illustrates that emission rates in conjunction with mine area are an important consideration and tend to give more accurate results. Many future mining developments are presented in terms of coal productivity rather than area to be mined. Therefore, it is suggested that when using emission values determined in this study a disturbed surface area be calculated based on thickness of coal seam, coal density, etc., for evaluating future coal mining impacts from coal productivity values.

Meteorological factors are an important consideration in assessing the particulate emissions from an open pit coal mine. Wind speed and direction are the most evident and were handled in some detail throughout the study analysis procedure. Another important meteorological parameter in evaluating "fugitive dust" emissions is precipitation. The implications of precipitation on reducing "dust" emissions are obvious. However, precipitation throughout the study period was non-existent. Therefore, the emission rate factors calculated in this study may represent a "worst-case" situation. Pedco Environmental (11) also assessed lignite coal mine emissions. Their results are somewhat lower than the values determined in this study, however, their results were estimated, not experimentally derived. This would also indicate that these study values do reflect a worst-case situation.

In reviewing the literature for emission factors from open pit coal mines, it was found that little information existed. This study was a first attempt at assessing the effect lignite mining operations have upon the air quality of North Dakota. A great number of variables exist in the uncontrolled environment. It was difficult to evaluate all of these variables within the monetary and time constraints given. However, the complexity of the subject and the limited information available does point out a need for increased research in the area of lignite mining impacts upon air quality.

As energy development expands in Western North Dakota, so will the need to know the impacts upon air quality. The information in this study, even though a first attempt, is useful in assessing those impacts and will be used in the decision-making process concerning future coal development in North Dakota.

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APPENDIX A

Mining Activities

Mine A

Production Activities During Study Period
July 6, 1976 to August 6, 1976

The major activities monitored at Mine A during the study period include:

1) Blasting
2) Coal Removal
3) Grading
4) Overburden Removal
5) Topsoil Removal
6) Haul Road Usage

These activities took place within an area of approximately 5.0 square miles of the total mine property (Figure A-1). The locations and approximate area of the above listed activities are shown in Figures A-2 through A-7. The total coal production figures were supplied by the mining company and are presented in Table A-1. All activities took place during the hours of 7:30 a.m. and 10:45 p.m., 5 days per week with the exception of reclamation activity (24 hrs/day - 5 days/week), and stripping of overburden (24 hrs/day - 7 days/week).

Area Of Major Mining Activity

Mine A

July-August 1976

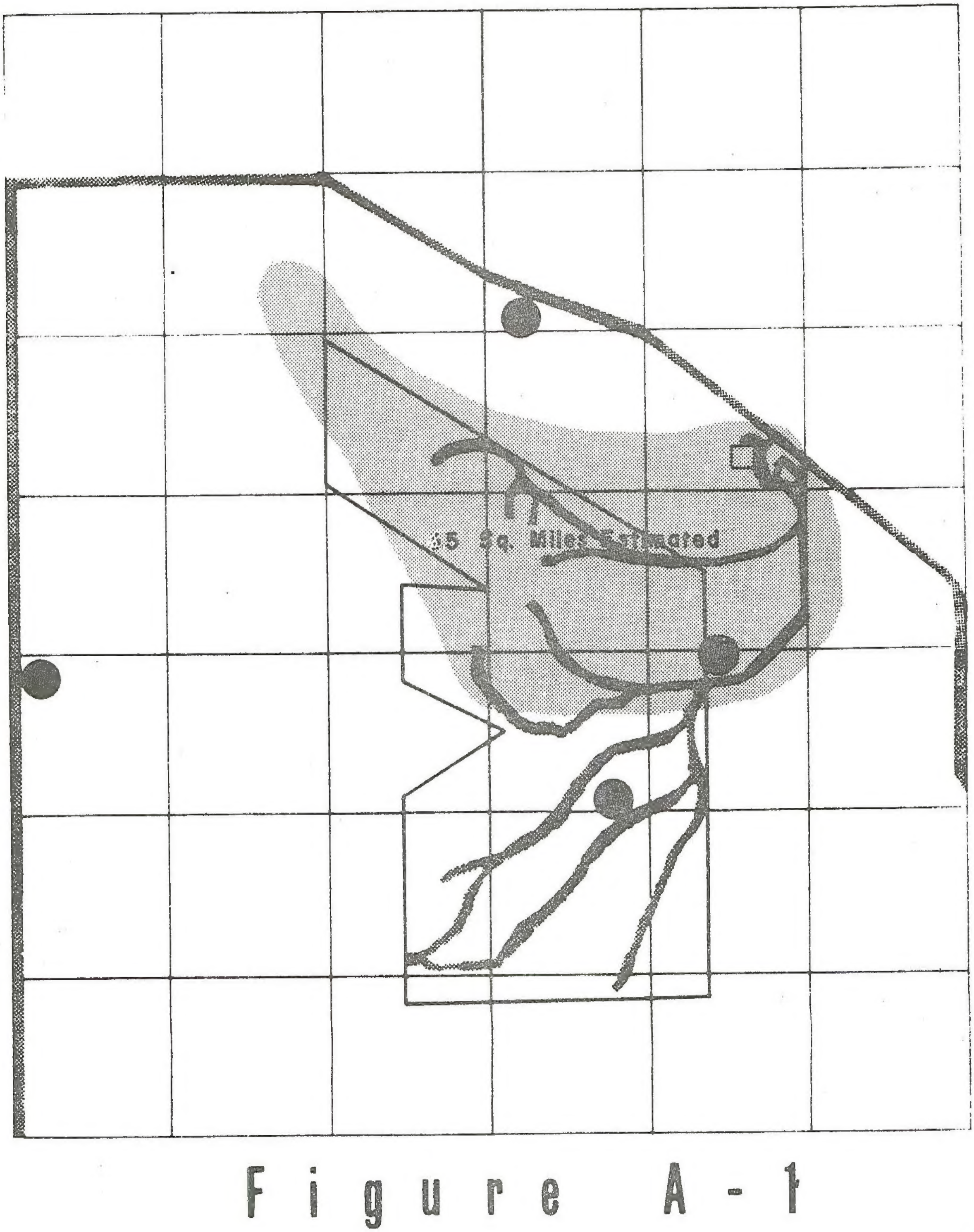

Figure A-1

Blasting Activity

Mine A

July-August 1976

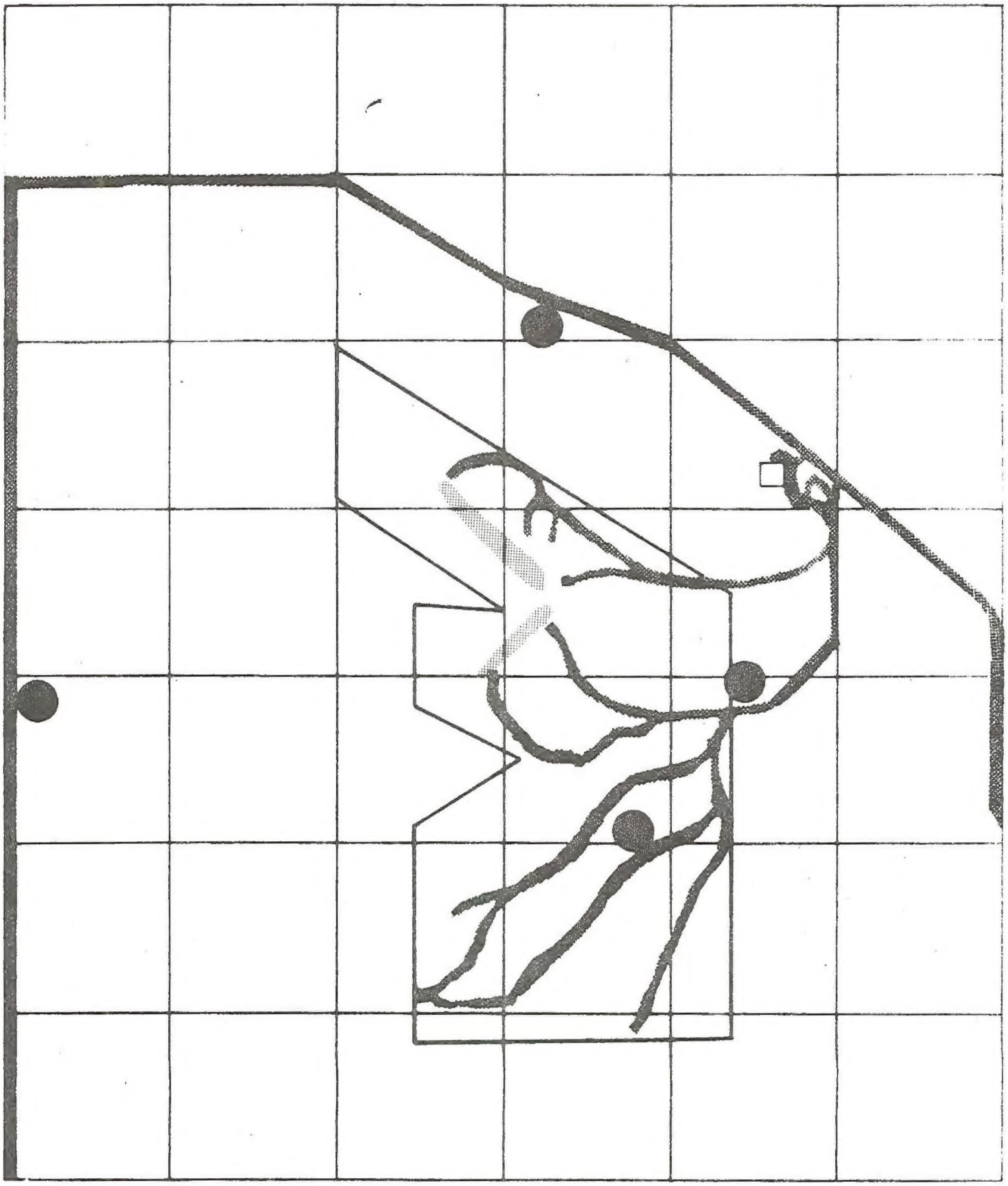

Figure A-2

Coal Removal Operations
Mine A
July-August 1976

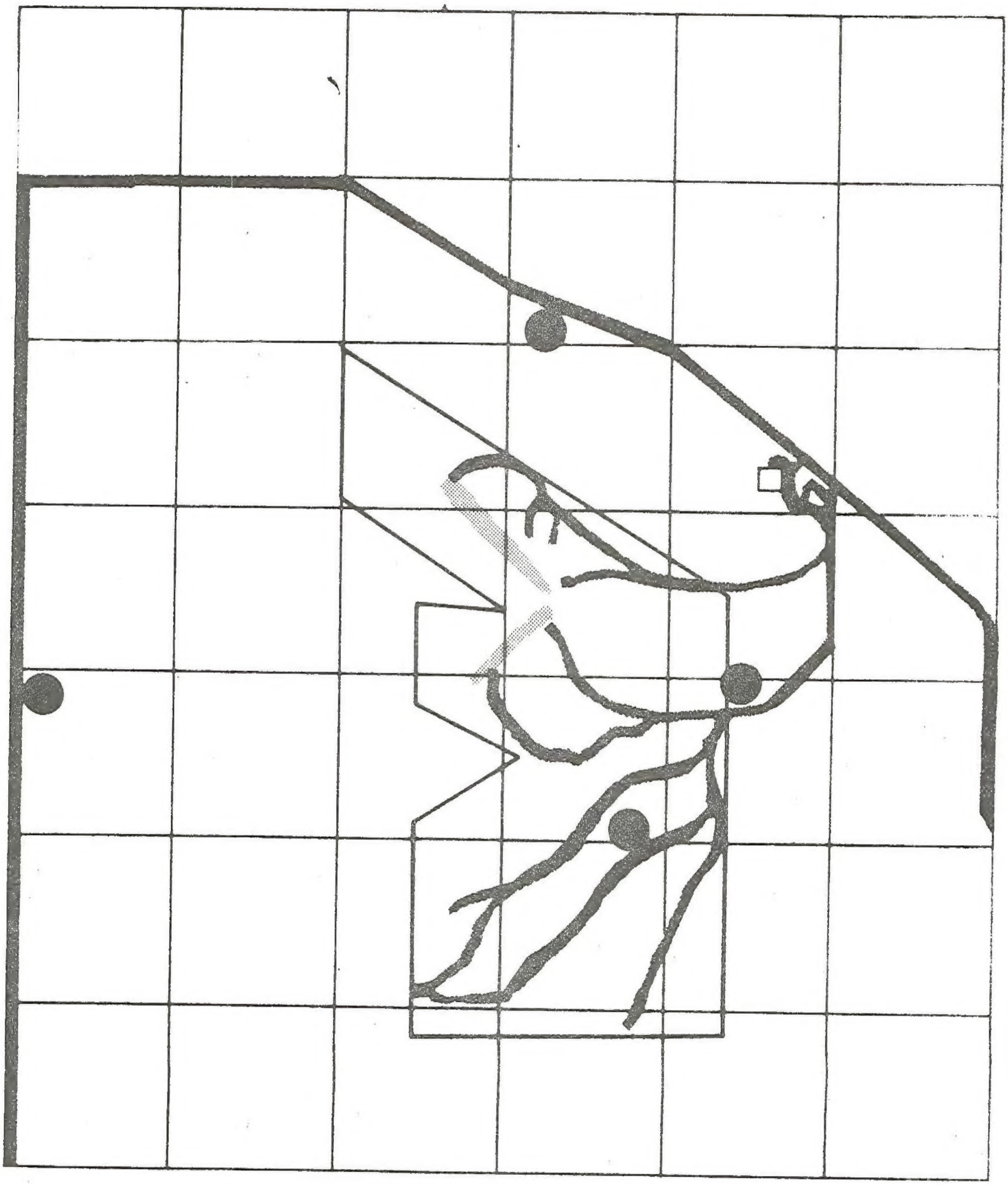

Figure A-3

Surface Grading Activity

Mine A

July - August 1976

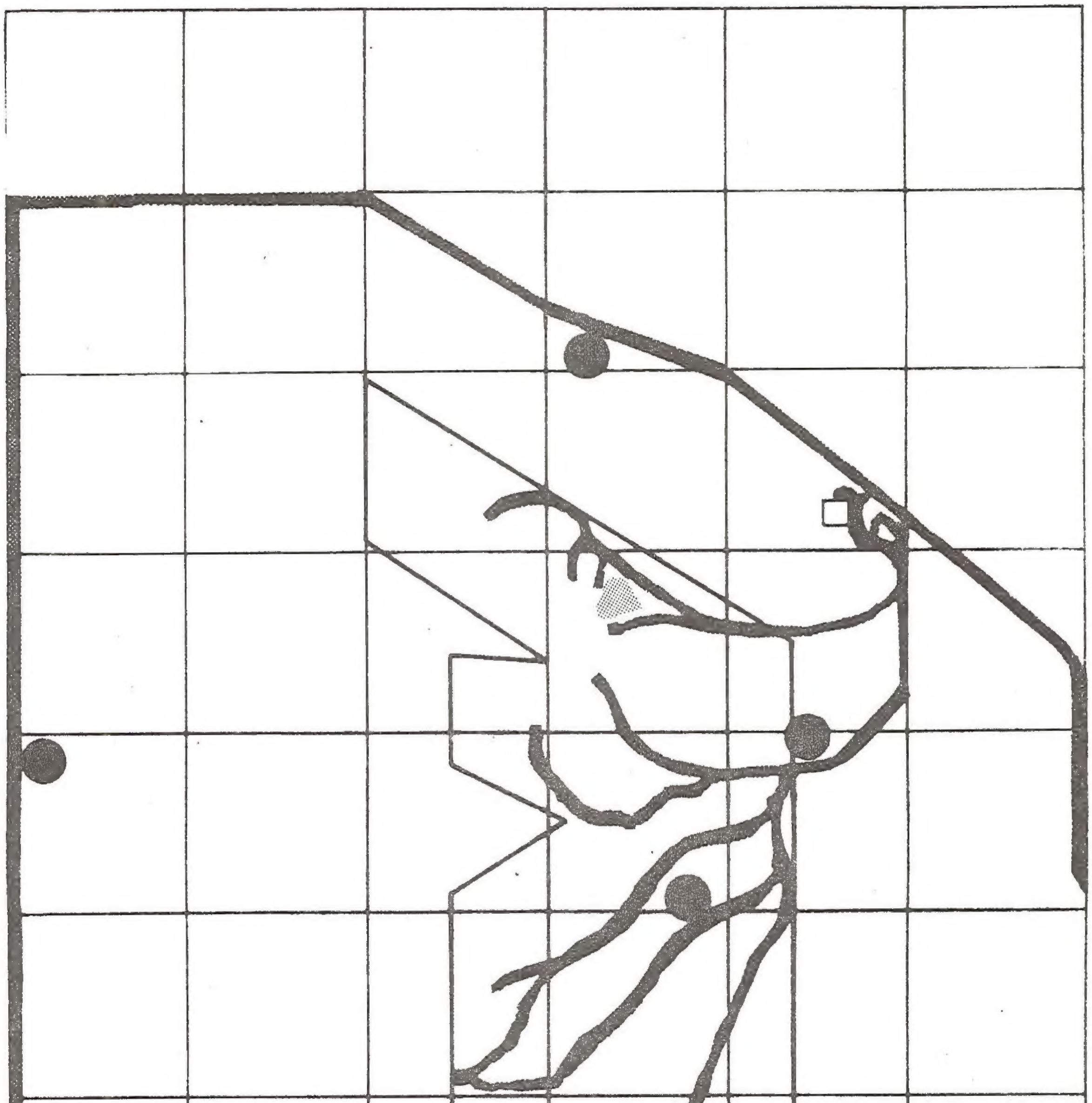

Figure A-4

Overburden Removal Operations
Mine A
July-August 1976

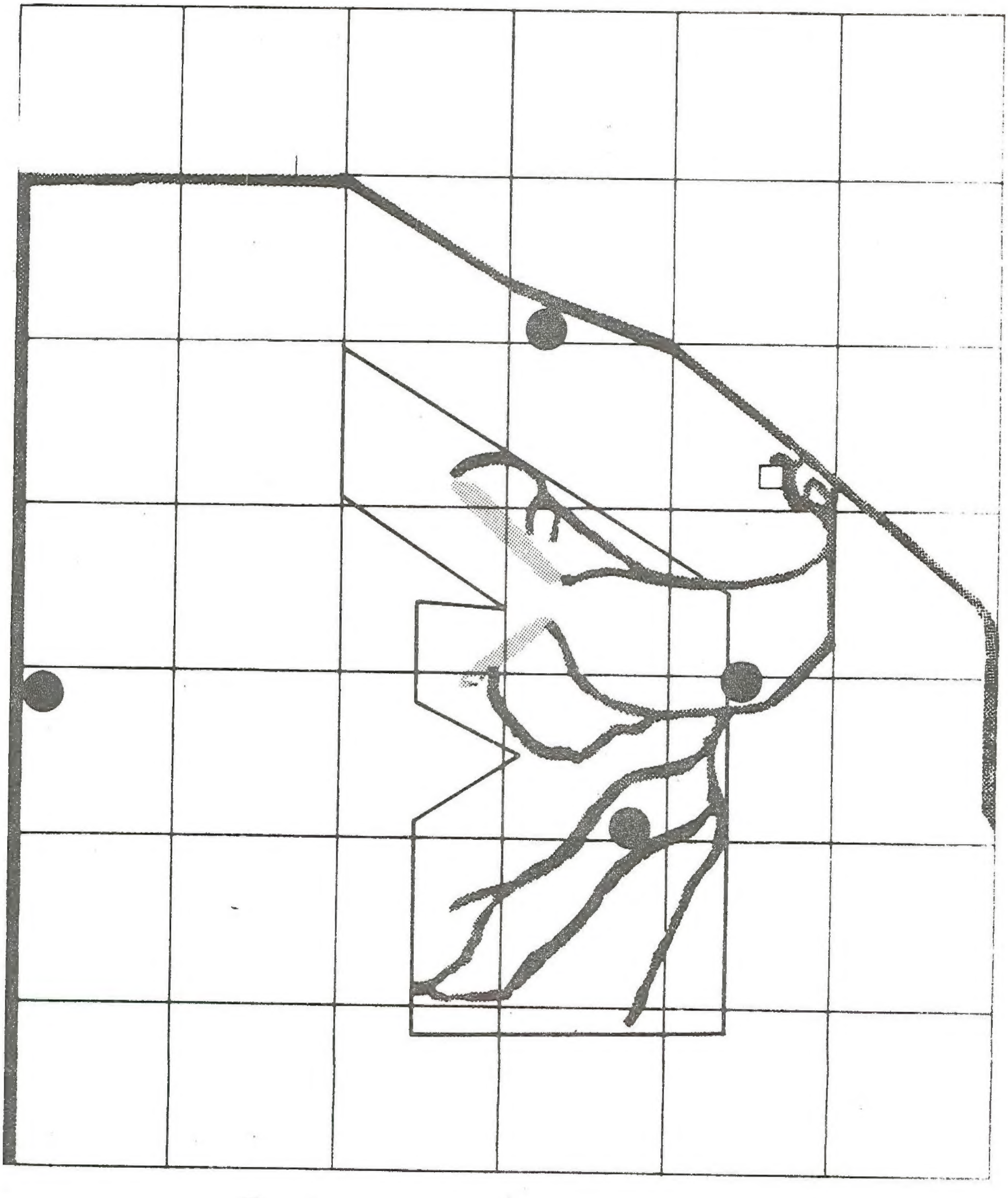

Figure A-5

Soil Removal And Replacement

Mine A

July-August 1976

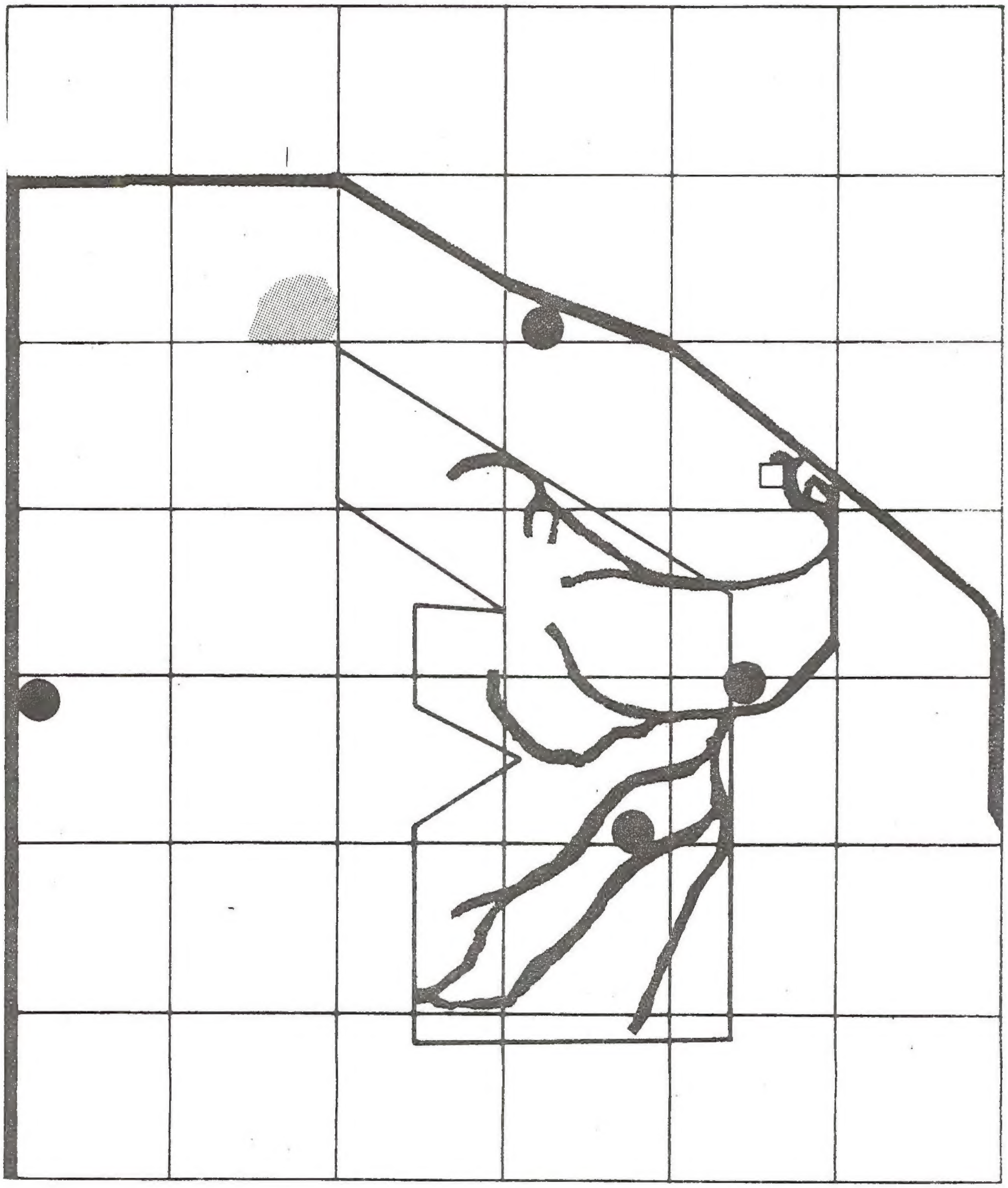

Figure A-6

Major Haul Road Usage
Mine A
July-August 1976

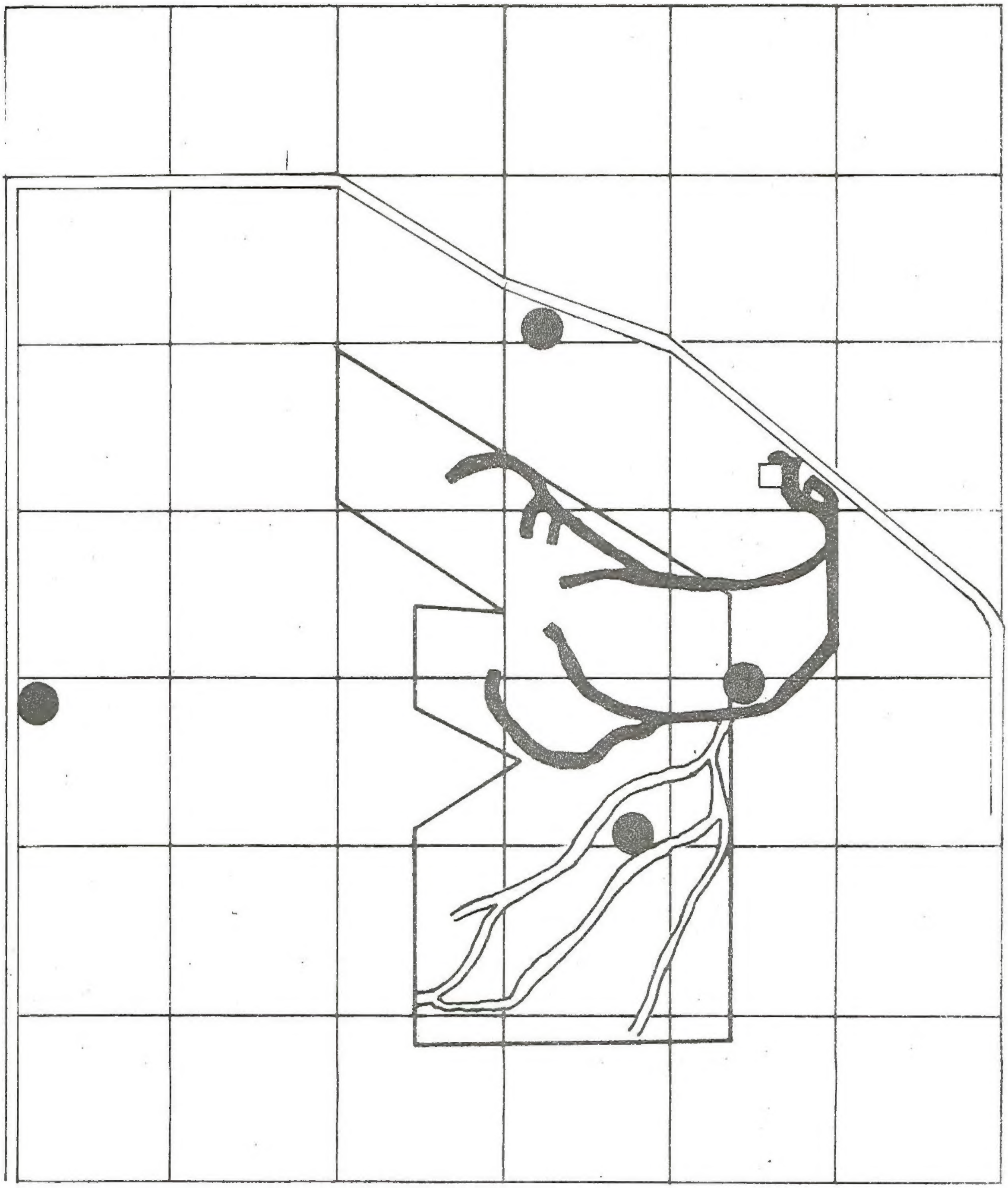

Figure A-7

TABLE A-1: Mine A

Daily Ton Haulage
July 6, 1976 to August 6, 1976

Day		Section (19)		Section (29)
July	6	4,080		12,580
	7	3,910		11,390
	8	1,360		10,370
	9	5,440		6,970
	10		No Loading	
	11		No Loading	
	12	4,080		10,200
	13	9,180		6,630
	14	2,550		11,220
	15	3,740		11,560
	16	5,610		7,530
	17		No Loading	
	18		No Loading	
	19	8,670		6,290
	20	4,250		12,920
	21	3,230		14,710
	22	520		15,060
	23	1,690		14,060
	24		No Loading	
	25		No Loading	
	26	3,570		13,920
	27	4,640		12,930
	28	3,430		10,650
	29	4,810		13,780
	30	3,400		12,840
	31		No Loading	
August	1		No Loading	
	2	3,570		11,430
	3	4,080		10,880
	4	9,010		3,740
	5	6,630		7,650
	6	5,270		8,500
Total		106,720		257,810
GRAND TOTAL				364,530

Mine B

Production Activities During Study Period
August 11, 1976 to September 11, 1976

The activities monitored at Mine B during the study period are as follows:

1) Blasting
2) Coal Removal
3) Grading
4) Overburden Removal
5) Topsoil Replacement
6) Subsoil Removal
7) Topsoil Removal
8) Haul Road Usage

All listed activities occurred within an area of the mine property comprising approximately 1.25 square miles (Figure A-8). The locations and approximate area of the operations are presented in Figures A-9 through A-14. Coal production figures were supplied by the company and are presented in Table A-2. The normal hours of total activities during the period were 8:00 a.m. to 5:00 p.m. - 5 days/week.

Area Of Major Mining Activity
Mine 8
August - September 1976

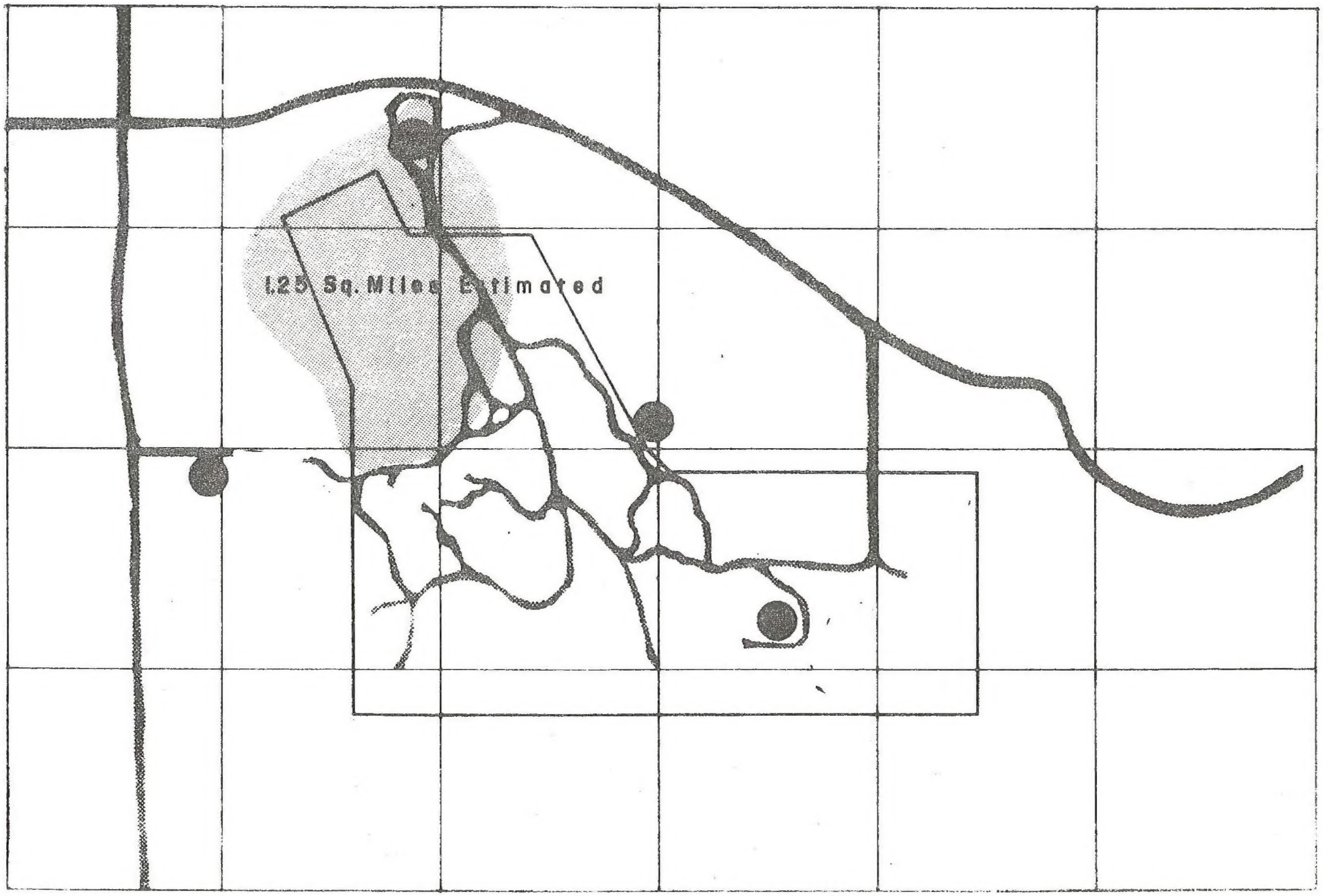

Figure A-8

Blasting Activity
Mine B
August-September 1976

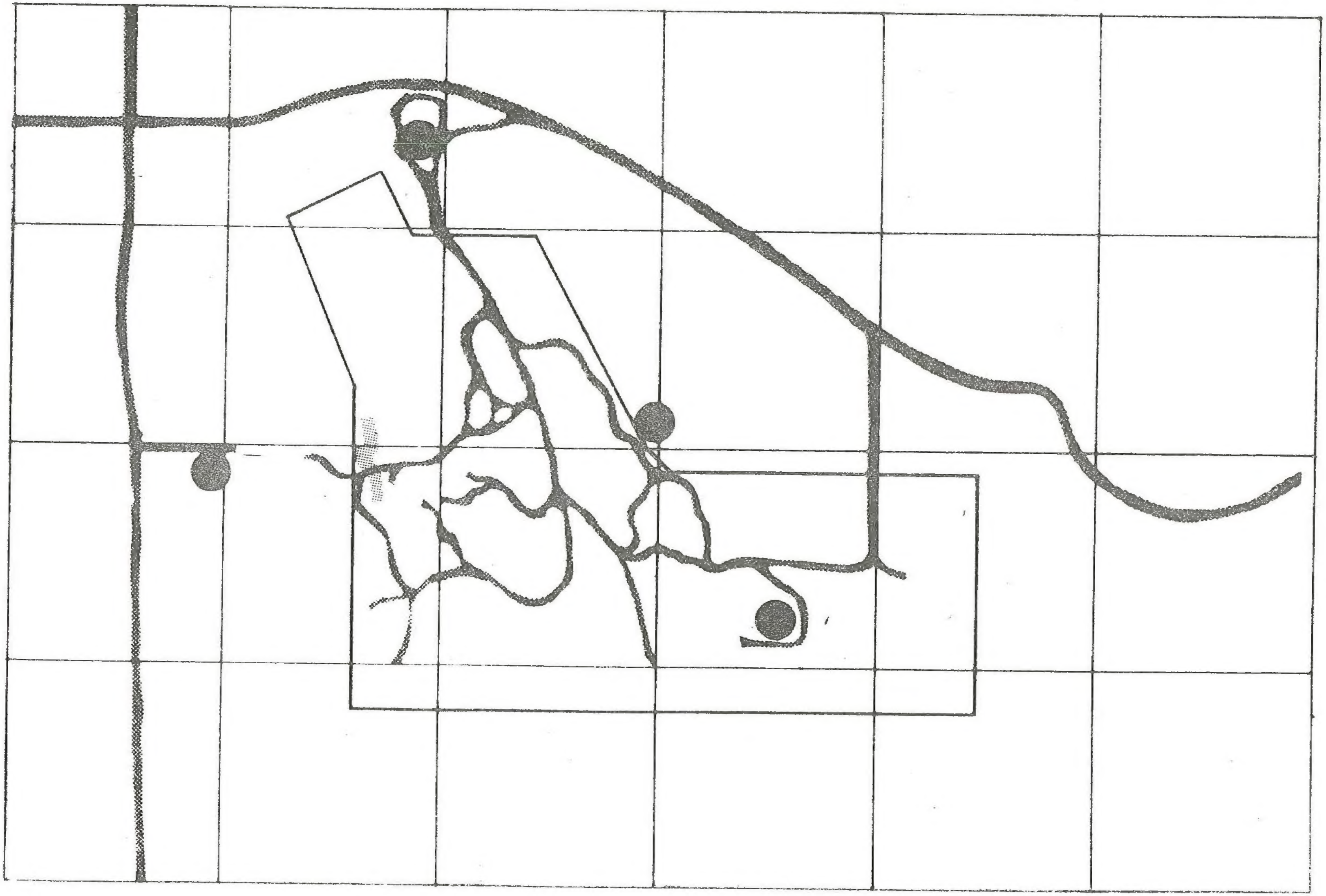

Figure A-9

Coal Removal Operations

Mine B

August - September 1976

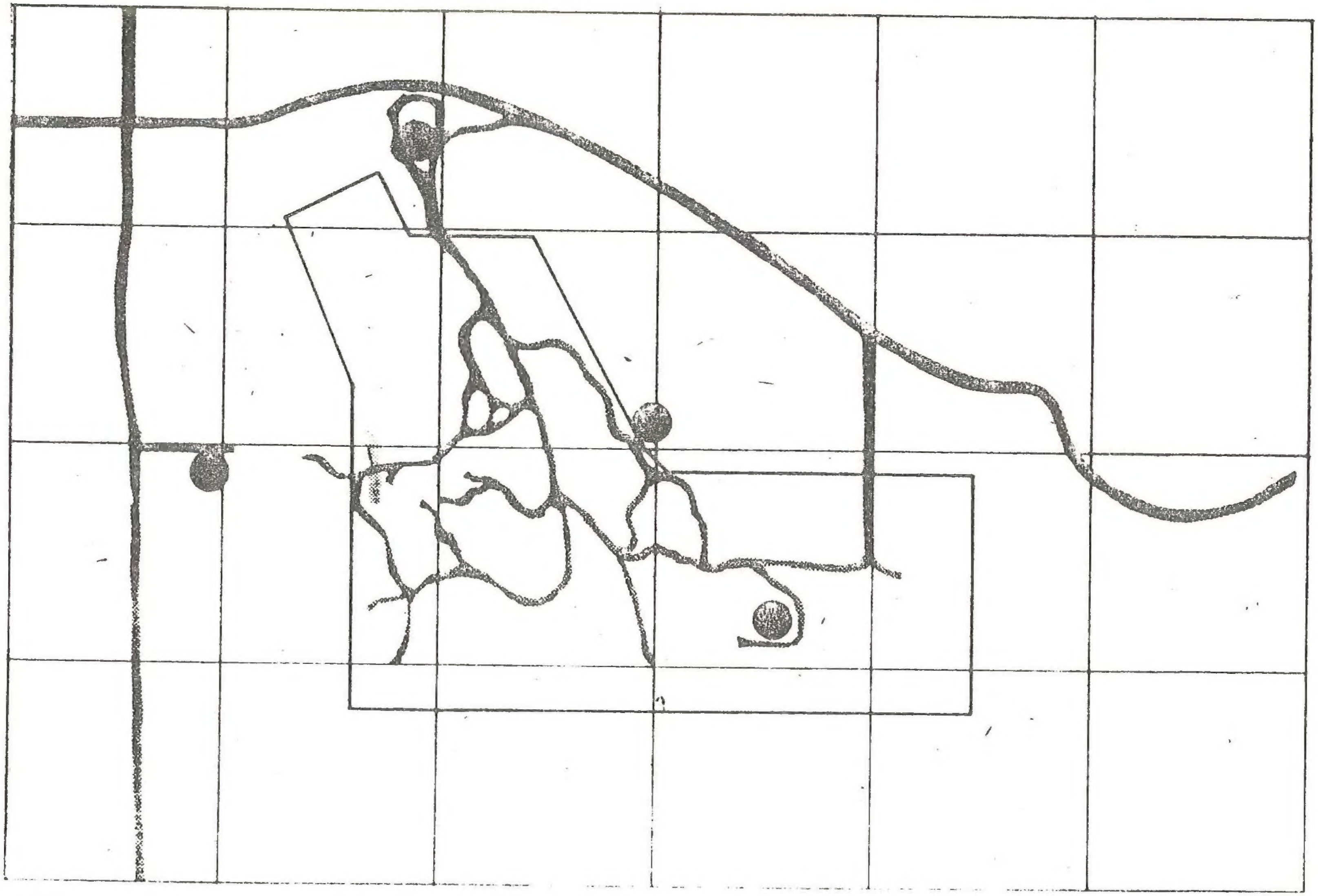

Figure A-10

Surface Grading Activity
Mine B
August-September 1976

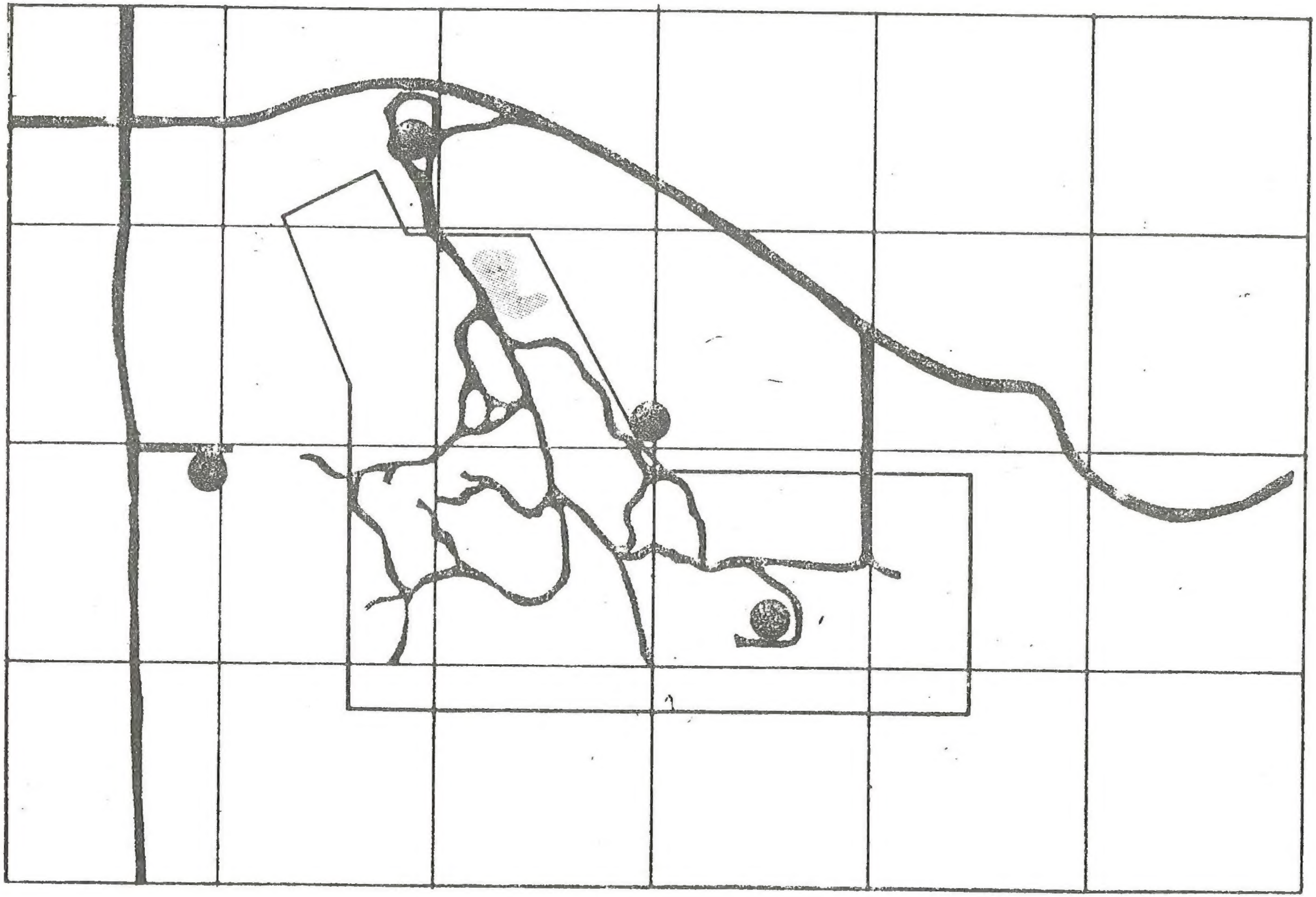

Figure A-11

Overburden Removal Operations

Mine B

August-September 1976

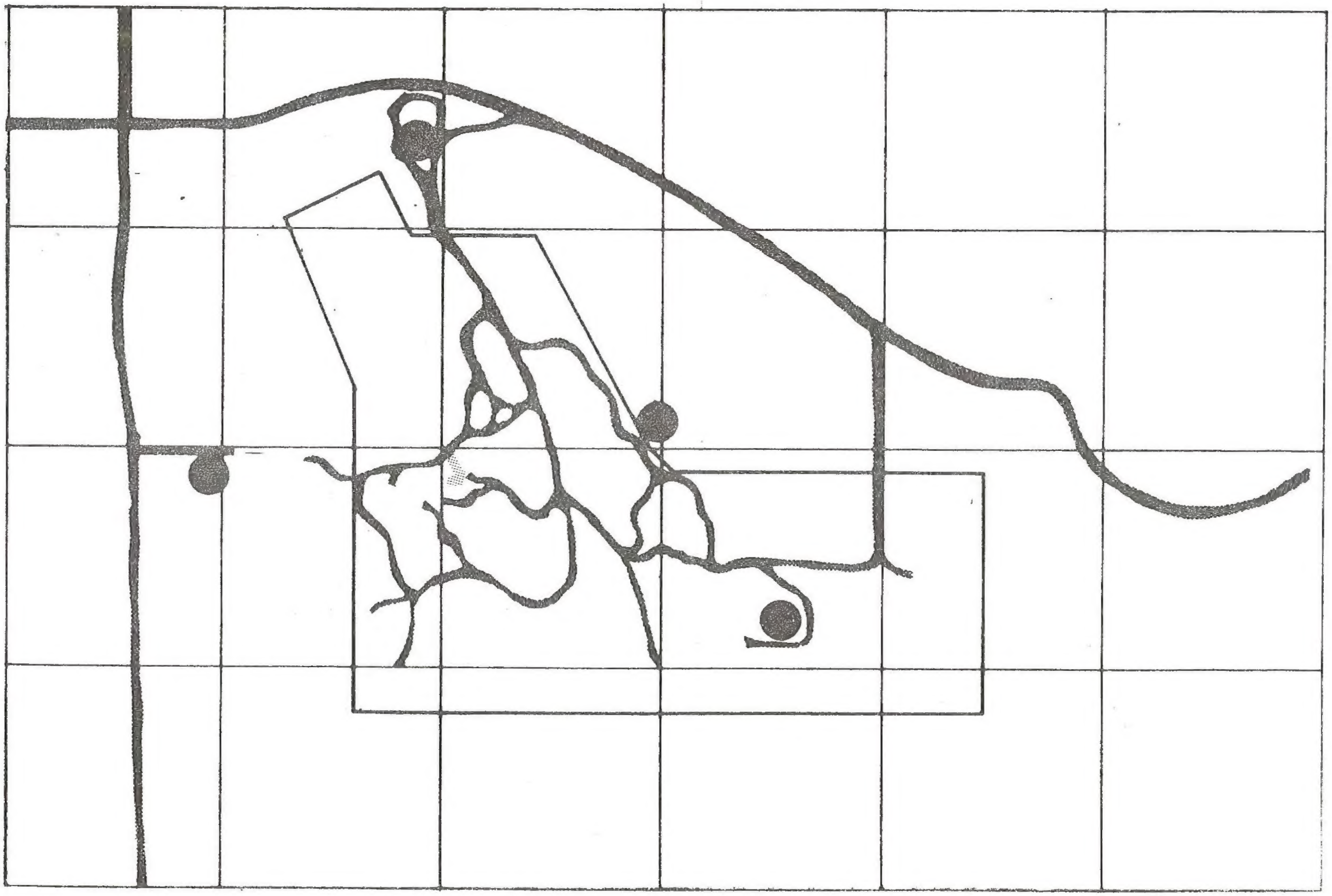

Figure A-12

Soil Removal And Replacement

Mine B

August - September 1976

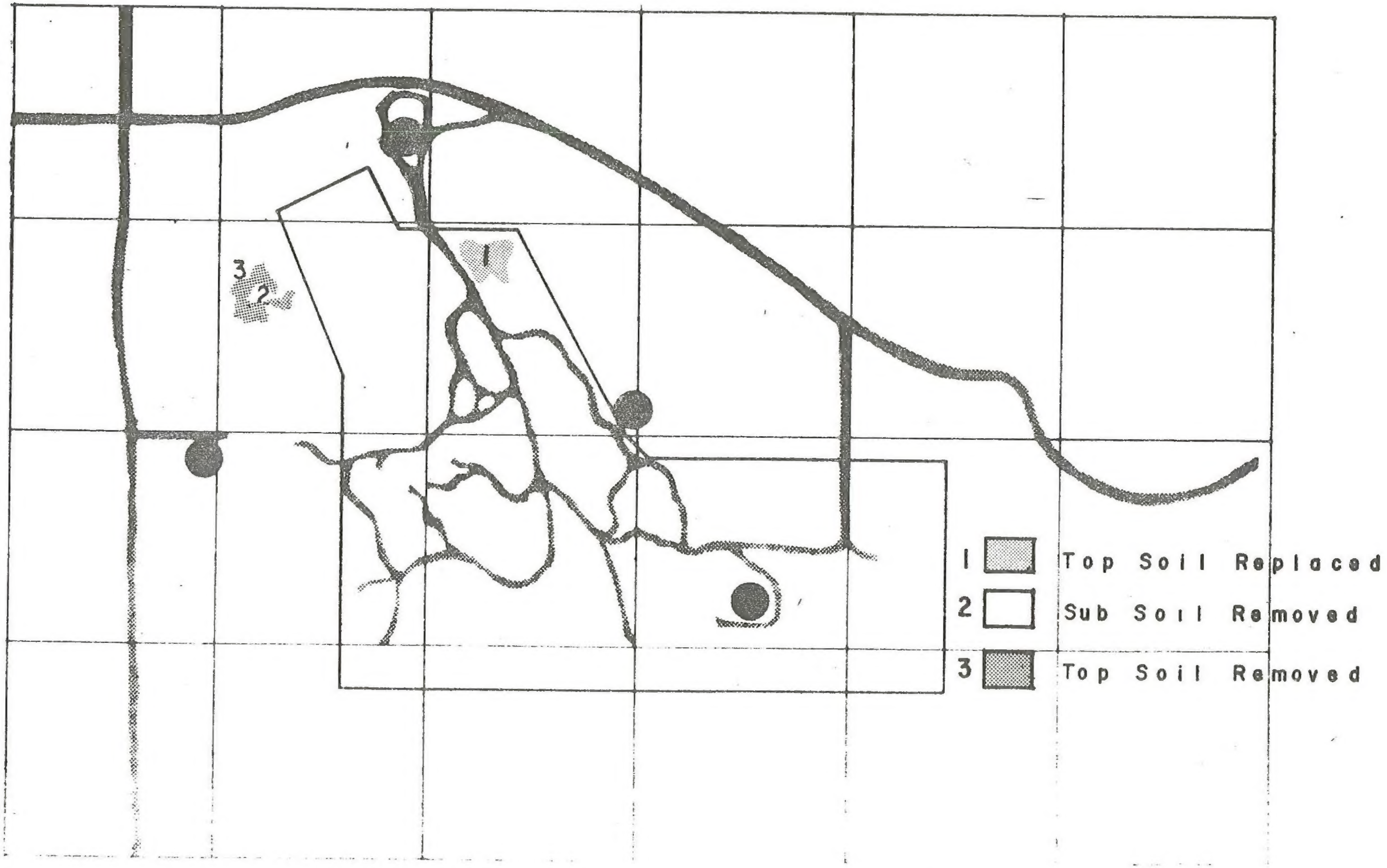

Figure A-13

Major Haul Road Usage

Mine B

August-September 1976

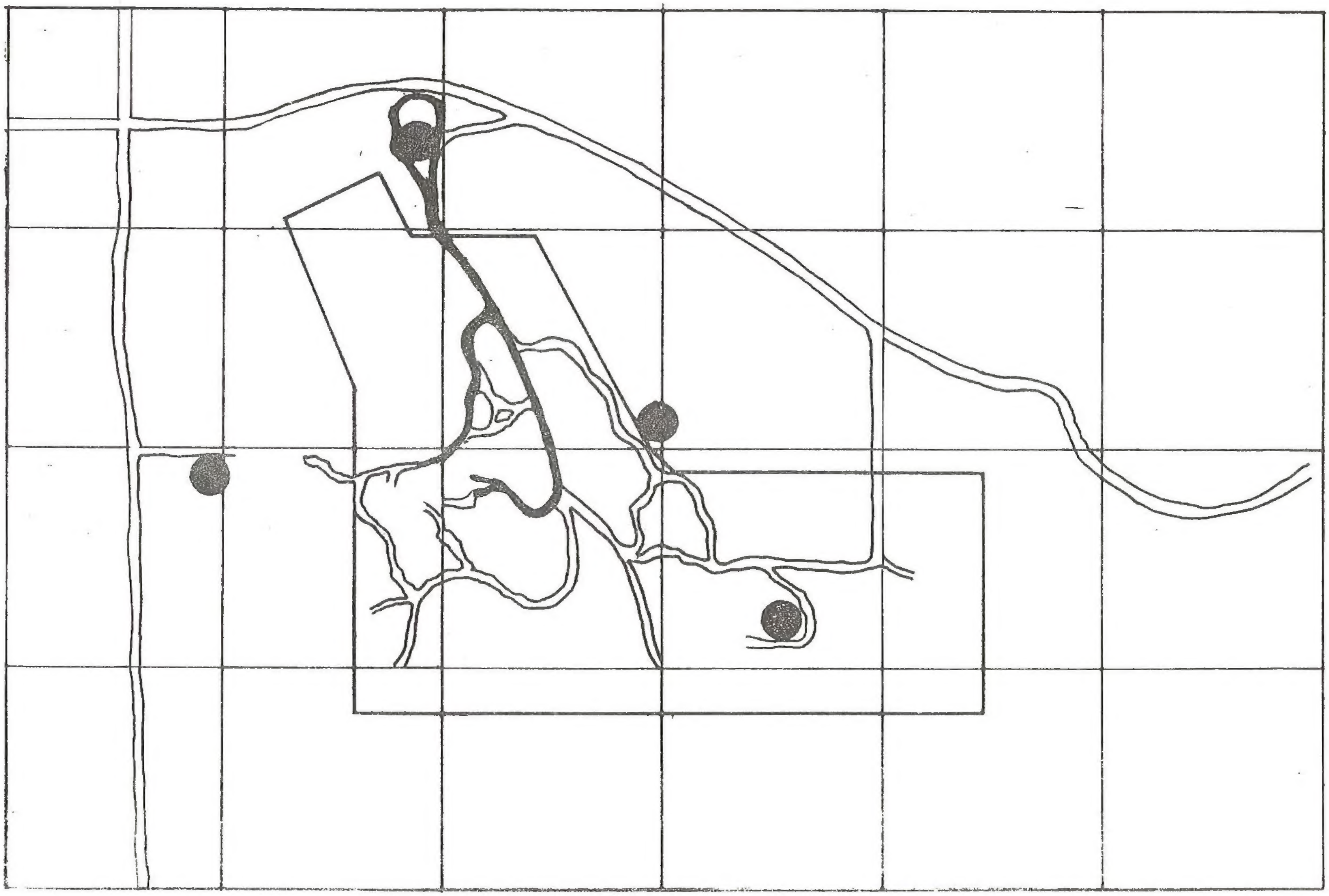

Figure A-14

TABLE A-2: Mine B

Daily Tonnage

Day	Tonnage	Day	Tonnage
8-11	4770	8-30	4439
8-12	4845	8-31	4672
8-13	4195	9-1	4025
		9-2	4121
		9-3	4022
8-16	6082	9-6	Holiday
8-17	5246	9-7	4295
8-18	3644	9-8	4864
8-19	1354	9-9	4970
8-20	7457	9-10	4917
		9-11	No Loading
8-23	6427		
8-24	4933		
8-25	4477		
8-26	4662		
8-27	4481		
TOTAL			102,898

APPENDIX B

Meteorological Data

METEOROLOGICAL DATA

July - August - September 1976

The primary focus of meteorological data collection activity was the recording of the windspeed and wind direction at each mine being studied. Tables B-1 and B-2 represent the data collected for Mine A and Mine B, respectively. Because of data voids due to equipment failure, the on-site information was supplemented with data from the National Weather Service Operation at Bismarck, North Dakota. (9) The NWS information was found to correlate quite well with recorded on-site meteorological data.

Tables B-3 and B-4 present the windspeed/wind direction percent frequency distribution in the general area of the study sites. This data was obtained from North Dakota State University. (7)

TABLE B-1: Windspeed/Wind Direction Data
Mine A

Time Interval	7-6*		7-7*		7-8*		7-9*		7-10*		7-11*		7-12*		7-13*		7-14*	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.			0		12	SE	0		5	SE	0		9	E	6	SSW	3	SW
1:00	5	W	0		8	ESE	0		18	N	0		9	ESE	12	NW	0	
2:00	5	SSE	0		6	E	0		14	WSW	0		9	ESE	6	NNE	0	
3:00	0		0		7	ENE	5	W	9	SE	0		9	E	17	WNW	0	
4:00	6	W	5	ENE	5	E	0		5	SE	5	ENE	8	E	12	WNW	0	
5:00	6	WNW	0		7	ESE	0		12	N	6	E	9	E	9	W	0	
6:00	6	WNW	0		6	ESE	0		0		6	ENE	6	E	17	NW	3	WSW
7:00	6	W	0		7	ENE	7	S	7	NW	9	ENE	8	E	13	WNW	0	
8:00	7	WNW	0		9	ENE	6	WNW	6	NNW	10	E	9	E	10	W	3	SSW
9:00	14	NW	6	E	9	ESE	6	N	6	W	8	NE	14	ESE	15	W	5	S
10:00	14	NW	6	SE	10	E	12	N	8	NNW	9	ENE	18	SE	13	W	9	SSW
11:00	13	NNW	8	SE	17	ESE	10	N	7	NW	9	E	23	SE	10	W	7	SSW
12:00 p.m.	8	N	7	ESE	17	ENE	7	N	8	NW	12	E	23	SE	14	WNW	6	S
1:00	13	N	7	SSE	25	E	9	N	13	W	8	ENE	20	SE	17	W	7	WNW
2:00	13	NNW	6	SW	18	E	7	W	13	NW	12	NE	24	SE	14	W	7	WNW
3:00	13	NW	6	ESE	19	ESE	9	NW	10	NW	14	SE	19	SSE	14	W	10	W
4:00	12	NNE	10	SSE	15	ESE	6	NW	9	N	12	ESE	23	SSE	14	W	13	WSW
5:00	10	N	10	SSE	13	E	7	N	12	N	10	ESE	21	SSE	14	WNW	12	NW
6:00	12	NNW	12	SE	13	ESE	4	ENE	7	N	14	E	22	SSE	10	W	18	SW
7:00	8	N	9	ESE	12	ESE	8	E	7	NE	13	E	12	SSE	9	WNW	7	W
8:00	7	N	9	ESE	7	ENE	8	ENE	0		12	E	9	ESE	7	NW	5	WNW
9:00	6	N	8	ESE	7	NE	7	ENE	5	ESE	13	E	7	SSE	8	WNW	7	NNW
10:00	6	ENE	7	ESE	6	E	6	E	0		9	E	14	S	6	WSW	12	N
11:00	6	ENE	9	ESE	0		6	N	0		12	E	8	SSE	0		14	N

*National Weather Service, Bismarck, North Dakota

Time Interval	7-15*		7-16		7-17		7-18		7-19		7-20		7-21		7-22		7-23	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.	9	N	0*		2	SE	12	SSE	10	SE	5	NNW	4	SSE	6	SE	1	SSW
1:00	6	NW	0*		2	SSE	12	SSE	3	ESE	8	NW	9	SSE	8	SE	0	
2:00	6	W	0*		7	ESE	16	S	3	WNW	5	NW	8	SE	12	SE	1	S
3:00	9	WNW	5	W*	6	E	13	SSE	2	SW	5	NW	9	SE	8	SE	0	
4:00	7	W	0*		1	N	17	SSE	2	S	4	NW	8	SSE	5	SE	1	S
5:00	7	W	0*		2	NNE	21	SSE	3	ESE	5	W	12	ESE	11	SSE	0	
6:00	12	NW	0*		1	W	19	SSE	3	WNW	5	W	14	ESE	6	S	0	
7:00	14	NW	0*		0		8	SSW	5	NW	6	W	17	SE	7	S	1	NNW
8:00	20	NW	7	SW*	3	NNE	4	SE	10	WNW	5	NW	18	SSE	12	W	3	NE
9:00	18	NW	7	SW*	5	NNE	2	SE	12	WNW	5	NW	21	SE	16	WNW	5	ENE
10:00	17	NW	8	SSW*	14	SSE	7	ESE	5	NW	5	NW	19	SSE	14	WNW	6	NE
11:00	17	NW	10	WNW	12	SSE	10	SE	4	NNW	6	NW	23	SSE	16	NW	7	NE
12:00 p.m.	17	NW	8	NW	13	SSE	6	SE	8	ENE	5	NNW	19	SSE	14	NW	8	NE
1:00	15	NW	9	NNW	15	SE	5	SE	6	N	7	NNE	24	SSE	21	NW	6	NE
2:00	15	NNW	8	N	12	SE	10	S	8	N	8	NE	25	SSE	19	NW	7	NE
3:00	14	NW	8	N	11	SSE	18	S	9	NE	5	N	21	SSE	19	WNW	5	NE
4:00	14	N	8	N	11	SSE	9	S	6	N	3	N	21	SSE	21	WNW	8	ENE
5:00	15	NNW	8	N	13	SSE	10	SSE	10	NNW	3	NW	20	SSE	15	WNW	6	NNE
6:00	15	NNW	5	N	16	SSE	13	ESE	12	NW	4	NW	19	SSE	13	NW	7	NE
7:00	12	NNW	6	N	17	SSE	13	ESE	5	S	3	NE	12	SSE	6	NW	6	ENE
8:00	8	N	2	N	13	SSE	10	SE	11	N	2	NE	7	SSE	4	NW	4	SE
9:00	5	NNE	3	SE	9	SE	2	ENE	7	NW	2	SE	10	SE	2	WNW	4	SSE
10:00	0		0		12	SE	5	SSW	5	NNW	3	S	12	ESE	1	SSW	10	ESE
11:00	0		4	S	13	SE	10	SE	6	NNW	4	S	16	SE	4	S	7	SE

TABLE B-1 continued

Time Interval	7-24		7-25		7-26		7-27		7-28		7-29		7-30		7-31		8-1	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.	5	SE	20	S	7	WNW	11	SE	7	WNW	17	S	3	S	3	W	6	SSE
1:00	6	SSE	19	S	7	W	12	ESE	6	WNW	7	WNW	1	S	7	SSE	3	SSE
2:00	8	SE	21	SW	7	W	13	SE	4	W	6	SW	1	SSW	6	SE	2	SSE
3:00	9	SSE	20	SSW	1	WNW	16	SSE	3	SE	7	ESE	2	WNW	5	SSE	1	SSW
4:00	10	ESE	20	SSW	0		16	SE	2	NNE	7	ESE	5	WNW	4	ESE	1	WSW
5:00	15	SE	4	W	0		19	SE	1	SSE	2	WSW	3	WNW	2	SE	1	SSE
6:00	13	SE	5	WNW	1	NW	20	ESE	1	SSE	1	SSE	5	WNW	8	ESE	2	ESE
7:00	12	ESE	7	WNW	1	NE	20	ESE	2	ENE	2	ENE	5	WNW	6	ESE	4	ESE
8:00	18	ESE	9	NW	4	NNW	18	ESE	3	NNE	5	WNW	6	NW	5	ESE	4	ESE
9:00	23	ESE	7	WNW	5	NNW	13	SSE	4	NNE	3	NNE	10	NNE	6	ENE	6	ENE
10:00	18	SSE	17	NW	6	NW	15	SSE	25	WSW	4	NW	9	NNE	10	ENE	10	ESE
11:00	19	SE	18	WNW	5	NNW	23	S	12	WSW	3	NNE	9	NNW	10	ENE	10	ENE
12:00 p.m.	18	SE	19	WNW	7	NE	25	S	10	SW	6	NW	10	NNE	7	ENE	8	ENE
1:00	18	SE	16	NW	7	NE	22	S	10	SW	4	NNW	9	NNW	6	E	9	ENE
2:00	16	E	15	NW	6	N			11	SSW	6	NNE	9	NNE	7	E	9	E
3:00	22	SSW	14	NW	4	NW			12	SSW	7	NE	10	NNE	8	E	13	E
4:00	21	SSW	13	NW	5	ENE	23	SSE	17	S	8	NNW	10	NNE	9	ENE	15	E
5:00	18	SSW	13	NNW	7	E	19	W	18	S	12	NNW	10	NE	8	ENE	16	E
6:00	13	SSW	12	NNW	10	ESE	9	NW	19	SSW	15	N	8	NE	9	ENE	15	ENE
7:00	14	S	8	NNW	9	ESE	7	NW	17	SSW	11	NNE	6	ENE	9	E	13	E
8:00	14	S	8	NNW	7	SSE	6	WNW	14	SSW	9	NNE	5	ENE	3	E	9	E
9:00	15	S	10	NNW	6	SE	12	WNW	15	SSW	5	N	0		1	SSE	4	SSE
10:00	17	S	10	NW	8	SE	9	WNW	18	S	4	N	1	SSW	3	S	3	SSE
11:00	18	S	6	WNW	9	SSE	11	WNW	18	S	3	ESE	1	SSW	4	SSE	4	SSE

TABLE B-1 continued

Time	8-2		8-3		8-4		8-5		8-6		8-7		8-8		8-9	
Interval	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.	5	SSE	9	SSE	5	WNW	11	ENE	5	SSE	12	SSE	9	ESE	7	SSE
1:00	5	SSE	10	SSE	8	WNW	13	ENE	7	SSE	16	SSE	7	ENE	11	SSE
2:00	5	SSE	12	S	3	WNW	10	ENE	5	SE	17	SSE	18	ESE	12	SE
3:00	6	SSE	10	S	7	WNW	7	ENE	2	ESE	17	ESE	20	ESE	17	ESE
4:00	7	SSE	10	S	7	WNW	10	ENE	5	SE	15	SSE	11	SE	23	ESE
5:00	4	SSE	5	SSE	7	WNW	6	ENE	8	SE	17	SSE	10	N	13	NNW
6:00	2	SSE	9	SSE	9	WNW	4	NNE	7	SSE	15	SE	9	NNE	9	NW
7:00	6	ESE	10	ESE	12	W	6	NNE	3	E	20	SE	7	WNW	8	NNE
8:00	9	ESE	15	SSE	9	WNW	7	ENE	6	E	22	SSE	6	NNE	7	NNE
9:00	10	ENE	19	SSE	6	NW	8	E	7	E	36	SE	14	ESE	7	NW
10:00	15	SSE	18	SSE	5	NNW	8	ENE	8	S	27	SSE	8	E		
11:00	16	SSE	19	SSE	7	NNW	10	E	9	ESE	29	SSE	5	ENE		
12:00 p.m.	16	SSE	18	SSE	8	NNW	10	NE	11	SE	31	SSE	5	N		
1:00	14	SSE	18	SSE	9	NNW	9	ENE	11	S	33	SSE	10	N		
2:00	15	SSE	17	SSE	8	NNW	8	NE	12	S	34	SSE	12	NW		
3:00	12	SSE	15	S	11	NNW	8	N	12	SSE	33	SSE	8	NW		
4:00	11	S	11	S	11	NNE	7	NW	14	SSE	31	SSE	8	NNE		
5:00	10	SSE	7	SSW	13	NNE	7	NW	13	SSE	31	SSE	7	N		
6:00	10	SSE	5	SW	9	NNE	7	ENE	13	SSE	32	SE	4	NNW		
7:00	9	ESE	3	SSW	11	NE	9	ENE	13	SSE	32	SSE	4	N		
8:00	9	SSE	0		9	ENE	1	SSE	12	SE	25	SSE	1	N		
9:00	5	ESE	3	W	15	ENE	3	S	10	SSE	21	SSE	1	S		
10:00	9	ESE	5	W	9	ENE	3	S	11	SSE	15	ESE	5	SSE		
11:00	13	SSE	3	W	8	ENE	3	SSE	10	SSE	12	S	7	SSE		

TABLE B-1 continued

TABLE B-2: Windspeed/Wind Direction Data
Mine B

Time Interval	8-11		8-12		8-13		8-14		8-15		8-16		8-17		8-18		8-19	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.	0*		2	W	10	ESE	9	E	8	ESE	13	SSE	9	SE*	0		0	
1:00	0*		0		9	ESE	5	E	5	E	14	SSE	9	SE*	6	N	5	N
2:00	0*		0		5	SSE	3	SE	9	SE	17	SSE	9	SSE*	0		4	SSE
3:00	5	SSW*	0		0		3	E	8	SE	19	SE	8	SE*	0		3	SSE
4:00	5	WSW*	0		5	ESE	6	ENE	9	SE	17	SSE	12	SSE*	0		3	ENE
5:00	5	SW*	0		6	ENE	6	ENE	8	ESE	17	SSE	8	SSE*	5	NE	5	SE
6:00	6	WSW*	0		7	E	7	E	8	SE	9	SE	7	SSE*	7	ENE	3	ESE
7:00	8	W*	0				8	E	9	SE	12	SE	8	E*	10	E	6	ESE
8:00	10	W*	0		7	ENE	9	E	14	SE	15	SSE	13	SE*	9	SE	5	SW
9:00	10	W*	5	S	7	NE	9	E	19	SSE	17	S	14	SSE*	10	E	8	W
10:00	14	NW*	5	W	12	ENE	14	ESE	16	SSE	19	S	13	SSE*	12	E	9	WNW
11:00	9	WNW*	7	NNW	9	ENE	14	E	16	SSE	21	S	14	SSE*	13	SSE	6	W
12:00 p.m.	8	WNW*	7	W	10	ENE	16	ESE	23	SSE	20	S	9	ESE*	9	SE	5	S
1:00	12	NW*	7	N	8	ENE	16	ESE	22	SE	17	S	9	SSE	6	NW	8	SW
2:00	9	NW*	7	WSW	7	E	16	SE	27	SSE	19	SSE	14	S	14	NW	7	W
3:00	20	NW*	8	SSW	8	ESE	15	ESE	24	SSE	22	SSE	13	SSE	9	NW	7	S
4:00	12	NW*	6	SW	9	E	13	ESE	25	SSE	19	SSE	13	SSE	9	N	7	SSW
5:00	10	WNW	5	NNW	10	ESE	10	SE	22	SSE	18	S	13	SSE	14	N	10	S
6:00	9	N	22	ENE	9	E	12	E	22	SSE	12	S*	8	S	13	NE	6	S
7:00	5	NNE	16	ENE	9	E	9	ESE	19	SSE	17	SSE*	0		8	NE	8	SE
8:00	5	NNE	13	E	8	E	8	ESE	17	SE	14	SSE*	4	W	6	N	6	SE
9:00	0		14	E	8	ENE	10	ESE	13	SE	14	SE*	7	ESE	5	NNW	7	SE
10:00	0		7	E	8	ENE	10	ESE	10	SE	18	SSE*	4	E	6	NW	10	SSE
11:00	14	ENE	8	E	8	ESE	5	E	13	SE	15	SSE*	0		0		9	ESE

*National Weather Service, Bismarck, North Dakota

Time	8-20		8-21		8-22		8-23		8-24*		8-25*		8-26*		8-27*		8-28*	
Interval	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.	9	SSE	0		0		7	NE	19	S	0		0		6	SSW	10	W
1:00	8	S	0		0		8	ENE	18	S	0		5	E	6	W	7	WNW
2:00	9	SSE	0		0		9	E	21	SSE	3	W	5	E	5	NW	5	WSW
3:00	8	SSE	0		0		8	E	10	S	5	W	5	ENE	8	WSW	0	
4:00	9	W	4	W	0		12	E	10	S	6	WSW	5	E	8	WSW	3	W
5:00	6	E	8	NW	0		9	E	8	S	3	WSW	5	E	14	W	6	NW
6:00	5	E	0		6	ENE	8	E	7	S	0		6	ENE	19	W	5	WSW
7:00	0		5	WNW	7	ENE	7	E	7	SSE	5	SW	6	ENE	15	W	5	W
8:00	7	SE	5	W	7	ENE	9	ESE	7	SW	0		7	E	15	W	6	W
9:00	7	SSE	5	W	7	ESE	14	SSE	9	WNW	5	WSW	12	SE	17	W	9	NW
10:00	8	SSW	8	NW	10	E	14	SSW	15	WNW	8	WNW	14	SSE	30	W	10	NNW
11:00	10	W	10	N	12	ESE	19	SSE	17	WNW	8	WNW	9	SSW	28	WNW	8	WNW
12:00 p.m.	10	WNW	13	NNW	12	E	22	SSE	12	WNW	10	W	13	SSE	28	W	7	N
1:00	14	W	12	WNW	14	ESE	24	SSE	13	WNW	8	WSW	14	WSW	30	WNW	6	W
2:00	9	WNW	12	NNW	12	E	25	S*	13	W	8	NW	15	W	28	W	6	W
3:00	15	W	8	NNW	12	ESE	19	S*	7	W	7	NW	14	WNW	24	WNW	7	SW
4:00	12	W	9	NNW	10	SE	22	S*	7	WNW	17	WNW	17	NW	29	WNW	5	SE
5:00	10	W	8	W	9	E	20	S*	5	SW	9	WNW	21	NW	30	WNW	6	ESE
6:00	7	W	5	NNW	14	ESE	17	SSE*	7	SSW	7	WNW	23	NW	21	WNW	8	ESE
7:00	9	N	6	N	7	ESE	18	SSE*	14	WNW	7	NNE	17	NW	23	WNW	9	E
8:00	6	NNW	6	N	8	ESE	14	SSE*	5	WSW	6	NNE	21	NNW	18	WNW	9	E
9:00	4	NNW	0		12	ESE	14	SSE*	7	N	5	NE	21	NW	14	W	8	E
10:00	6	N	0		9	E	13	SSE*	7	NNW	5	E	21	NNW	10	W	9	E
11:00	0		0		0		19	S*	0		6	E	15	NNW	10	W	7	ESE

TABLE B-2 continued

Time	8-29*		8-30*		8-31		9-1		9-2		9-3		9-4		9-5		9-6	
Interval	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.	8	ESE	7	NE	0*		12	SSE*	15	E	6	NW	2	W	2	SSE	2	SE
1:00	7	E	3	E	0*		8	SSE*	10	ESE	3	WNW	1	W	2	SSE	4	SSE
2:00	6	E	0		7	W*	10	ESE*	7	SE	6	WNW	1	W	1	W	2	SSE
3:00	7	E	3	S	14	N*	8	ENE*	8	SE	5	WNW	1	SE	4	SSE	2	WNW
4:00	7	E	0		7	E*	10	ENE*	6	SSE	6	WNW	1	SE	2	NE	7	SSW
5:00	7	E	3	NE	8	NNW*	8	E*	2	SSE	6	WNW	2	S	3	ENE	12	S
6:00	6	E	3	ENE	6	NNW*	9	E*	5	ESE	6	WNW	2	SSW	1	WNW	8	S
7:00	8	E	6	ENE	8	NE*	15	E*	7	SSE	7	WNW	3	SSW	1	W	7	SSE
8:00	7	ESE	7	ENE	10	NE*	15	SE*	11	SSE	10	WNW	16	SSE	2	SE	7	SSE
9:00	9	SSE	7	E	10	NE*	15	SE*	11	SE	17	WNW	23	SSE	9	ESE	13	SE
10:00	7	S	8	E	12	ENE*	12	SE*	18	SSW	26	NW	22	SSE	12	SW	18	SSE
11:00	5	S	14	ESE	15	ENE	14	E	28	SSW	23	NW	24	SSE	9	SW	38	S
12:00 p.m.	5	W	10	ESE	15	ENE	17	ENE	27	SSW	23	WNW	20	SSE	7	WSW	45	S
1:00	4	E	7	ENE	14	E	16	ENE	21	SW	29	WNW	18	SSE	8	WNW	44	SSE
2:00	6	W	9	E	12	E	17	NE	16	SW	30	NW	13	SSE	9	WNW	45	SSE
3:00	6	W	12	E	12	E	14	ENE	26	WNW	24	NW	8	S	12	WNW	41	SSE
4:00	12	NNW	12	ESE	10	SE	10	E	28	NW	23	NW	6	SE	10	WNW	33	SSE
5:00	12	NNE	9	ESE	9	E	9	ENE	28	NW	20	NW	5	SW	9	WNW	25	SSE
6:00	12	NNW	12	ENE	10	SE	13	ENE	25	NW	15	NW	6	W	8	WNW	17	SSE
7:00	8	NNE	8	ENE	8	ESE	20	ENE	23	NW	15	NW	7	SSW	4	WNW	21	SSE
8:00	7	NE	7	ENE	10	ESE	21	E	35	NNW	1	NNW	5	S	1	WNW	12	SSE
9:00	7	NE	5	E	8	SE	21	E	18	NW	6	NNW	1	SSW	3	WNW	18	W
10:00	7	ENE	5	N	6	ESE	19	E	8	NW	1	NW	1	W	0		19	WNW
11:00	8	ENE	7	N	8	SSE	17	E	9	WNW	1	SE	1	SE	2	ESE	30	NW

TABLE B-2 continued

Time Interval	9-7		9-8		9-9		9-10		9-11		9-12	
	S	D	S	D	S	D	S	D	S	D	S	D
12:00 a.m.	27	NW	3	NNW	2	WNW	3	NNW	1	S	17	S
1:00	18	NW	2	E	1	WNW	2	SE	0		19	SSE
2:00	23	NW	4	NNW	2	N	4	SE	2	SE	9	SSW
3:00	28	NW	8	WNW	2	S	4	ESE	3	WNW	6	SSE
4:00	32	NW	6	WNW	1	W	2	ESE	1	ESE	14	SE
5:00	24	NW	8	WNW	2	SSW	3	ESE	0		3	ENE
6:00	14	WNW	8	WNW	0		4	ESE	1	W	6	S
7:00	15	WNW	12	WNW	1	SSW	2	SE	4	S	4	S
8:00	14	WNW	10	WNW*	4	SSW	1	SE	6	SSW	2	W
9:00	11	WNW	10	W*	1	SSW	6	SSW	10	S	3	SW
10:00	7	WNW	15	WNW*	4	SSW	13	SSW	8	S	5	WNW
11:00	12	WNW	28	WNW	11	SSW	10	SSW	10	SSW	14	NW
12:00 p.m.	16	WNW	17	WNW	8	W	10	SSW	10	SSW	27	NNW
1:00	16	WNW	18	WNW	9	WNW	12	SSW	13	SSW	25	NNW
2:00	15	WNW	21	WNW	10	WSW	12	WSW	15	S	10	WNW
3:00	16	WNW	20	WNW	9	W	11	SW	15	SSW	13	WNW
4:00	14	WNW	28	NW	8	WNW	10	SW	15	SSW	16	NNW
5:00	15	WNW	21	NW	10	WNW	8	SW	18	SSE	12	WNW
6:00	12	WNW	18	NW	8	WSW	6	WSW	20	SSE	20	NNW
7:00	6	WNW	14	NW	6	WSW	1	WNW	13	S	25	NW
8:00	5	WNW	8	WNW	4	WSW	2	WNW	6	SSE	15	NW
9:00	4	NW	4	NW	8	SW	3	WNW	13	SSE	11	NW
10:00	8	NW	2	WNW	9	SSW	1	WSW	14	SSE	13	NW
11:00	6	NW	2	NW	11	SSW	1	WSW	16	SSE	9	NNW

TABLE B-2 continued

WIND SPEED / WIND DIRECTION PER CENT FREQUENCY DISTRIBUTION

NOPL METEOROLOGICAL TOWER

NO SPECIAL CONDITIONS

JULY

165 FT

PER CENT COMPLETENESS OF WIND SPEEDS = 75.4
PER CENT COMPLETENESS OF WIND DIRECTIONS = 66.1

	WIND SPEED (MPH)								
DIRECTION	1 - 3	4 - 7	8 - 11	12 - 15	16 - 20	21 - 25	> 25	TOTAL	MEAN SPEED
N	0.10	0.61	1.53	1.12	0.41	0.41	0.00	4.17	11.9
NNE	0.20	0.92	1.42	2.44	1.63	0.51	0.41	7.53	13.7
NE	0.00	0.61	0.81	1.22	0.41	0.10	0.00	3.15	11.6
ENE	0.00	0.20	0.31	0.71	0.81	0.20	0.00	2.75	14.1
E	0.00	0.31	0.81	2.03	3.05	1.83	0.10	8.14	16.8
ESE	0.00	0.31	0.61	1.83	4.37	3.05	0.81	10.99	18.5
SE	0.00	0.61	1.53	2.75	3.05	4.27	4.68	16.89	19.9
SSE	0.00	0.41	2.34	1.93	4.68	2.44	0.41	12.21	16.5
S	0.00	0.61	0.31	0.41	1.22	1.22	0.41	4.17	17.4
SSW	0.00	0.31	0.10	0.31	0.41	0.92	0.10	2.14	18.0
SW	0.00	0.10	0.71	1.93	0.81	0.61	0.31	4.48	15.5
WSW	0.00	0.10	0.51	1.02	1.12	0.00	0.00	2.75	14.6
W	0.10	0.71	0.51	1.02	0.92	0.41	0.00	3.66	13.6
WNW	0.00	0.31	1.32	1.12	1.12	1.93	0.31	6.10	16.7
NW	0.00	0.31	1.22	1.83	0.81	0.31	0.71	5.70	15.2
NNW	0.00	0.61	0.81	1.02	1.32	0.92	0.51	5.19	16.5
TOTAL	0.41	7.53	15.36	22.69	26.14	19.13	8.75	100.00	16.1
MEAN SPEED	2.4	5.7	9.5	13.3	18.2	23.1	27.5		

PER CENT FREQUENCY OF CALMS = 0.00

TABLE B-3

WIND SPEED / WIND DIRECTION PER CENT FREQUENCY DISTRIBUTION

NGPL METEOROLOGICAL TOWER
NO SPECIAL CONDITIONS
AUGUST
165 FT

PER CENT COMPLETENESS OF WIND SPEEDS = 88.9
PER CENT COMPLETENESS OF WIND DIRECTIONS = 88.0

	WIND SPEED (MPH)							
DIRECTION	1 - 3	4 - 7	8 - 11	12 - 15	16 - 20	21 - 25	> 25	TOTAL	MEAN SPEED
N	0.08	0.38	1.53	1.22	0.08	0.38	0.31	3.98	13.2
NNE	0.00	0.15	1.38	1.22	0.99	0.23	0.23	4.21	14.2
NE	0.00	0.61	1.15	1.84	1.07	0.54	0.00	5.20	13.3
ENE	0.08	0.15	1.07	1.30	2.45	0.61	0.08	5.74	15.6
E	0.00	0.23	1.38	1.91	2.75	1.53	0.31	8.11	16.4
ESE	0.08	0.46	1.22	1.68	2.45	1.15	0.08	7.12	15.2
SE	0.00	0.46	2.07	2.14	1.76	4.59	3.29	14.31	20.4
SSE	0.00	0.69	0.61	3.06	2.60	3.06	2.52	12.55	19.5
S	0.00	0.38	0.61	2.60	2.14	0.69	0.77	7.19	16.6
SSW	0.00	0.31	0.23	0.23	0.15	0.23	0.00	1.15	13.3
SW	0.00	0.15	0.69	0.15	0.15	0.00	0.00	1.15	10.3
WSW	0.00	0.46	0.99	0.61	0.31	0.00	0.00	2.37	10.9
W	0.00	0.54	1.76	2.14	2.37	0.46	0.38	7.65	14.6
WNW	0.00	0.69	1.45	2.22	1.68	0.61	1.45	8.11	18.5
NW	0.08	0.84	1.68	1.45	1.68	1.07	0.69	7.50	15.4
NNW	0.00	0.31	1.45	0.92	0.54	0.15	0.31	3.67	13.5
TOTAL	0.31	6.81	19.28	24.71	23.18	15.30	10.41	100.00	16.4
MEAN SPEED	3.0	6.0	9.6	13.6	17.7	23.0	31.0		

PER CENT FREQUENCY OF CALMS = 0.00

TABLE B-4

WIND SPEED / WIND DIRECTION PER CENT FREQUENCY DISTRIBUTION

NGPL METEOROLOGICAL TOWER
NO SPECIAL CONDITIONS
SEPTEMBER

DETERMINATION OF PARTICULATE EMISSION FACTOR FROM LIGNITE MINING OPERATIONS

APPENDIX C

Site Specific Air Quality Data

SITE SPECIFIC AIR QUALITY
FIELD DATA

The raw field information presented in the following tables constitutes the base data utilized for the emission factor calculations. Table C-1 shows the values obtained for settled particulate in tons per square mile per month at each sampling point. Table C-2 presents the suspended particulate concentrations obtained for each sampling point at Mine A. Table C-3 comprises a statistical summary of the suspended particulate concentrations for each sample site during the study period at Mine A.

The suspended particulate matter concentrations for each sample site at Mine B are presented in Table C-4. The statistical summary of Mine B suspended particulate concentrations for each sample site is presented in Table C-5.

TABLE C-1: Settled Particulate Tons/mi^2/month

Site #	Mine A[1]	Mine B[2]
1	25.25	9.87
2	18.97	11.03
3	27.06	4.40
4	6.93	20.34

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[1] Collection Period 7-6 to 8-6, 1976

[2] Collection Period 8-11 to 9-11, 1976

HL3020AA

TABLE C-2: NORTH DAKOTA STATE DEPARTMENT OF HEALTH
AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

Sample Site A-1

STATION NO. 350040001

		PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
	PARAMETER CODE	12602	11101	12403	12306	12702	11302
	METHOD CODE	91	91	92	93	91	91
	UNIT CODE	61	01	01	01	01	30
SAMPLE DATE	FILTER NO.		MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
7- 6-76	760464	0.0	58.	0.0	0.0	0.0	0.0
7- 7-76	760414	0.0	32.	0.0	0.0	0.0	0.0
7- 8-76	760313	0.0	59.	0.0	0.0	0.0	0.0
7- 9-76	760106	0.0	25.	0.0	0.0	0.0	0.0
7-12-76	760090	0.0	31.	0.0	0.0	0.0	0.0
7-13-76	761750	0.0	21.	0.0	0.0	0.0	0.0
7-14-76	761747	0.0	33.	0.0	0.0	0.0	0.0
7-15-76	761743	0.0	29.	0.0	0.0	0.0	0.0
7-16-76	761739	0.0	26.	0.0	0.0	0.0	0.0
7-19-76	761734	0.0	32.	0.0	0.0	0.0	0.0
7-20-76	761730	0.0	27.	0.0	0.0	0.0	0.0
7-21-76	761728	0.0	43.	0.0	0.0	0.0	0.0
7-22-76	761724	0.0	44.	0.0	0.0	0.0	0.0
7-23-76	761720	0.0	40.	0.0	0.0	0.0	0.0
7-26-76	761714	0.0	25.	0.0	0.0	0.0	0.0
7-27-76	761769	0.0	31.	0.0	0.0	0.0	0.0
7-28-76	761792	0.0	18.	0.0	0.0	0.0	0.0
7-29-76	761788	0.0	30.	0.0	0.0	0.0	0.0
7-30-76	761785	0.0	29.	0.0	0.0	0.0	0.0
8- 2-76	761779	0.0	22.	0.0	0.0	0.0	0.0
8- 3-76	761775	0.0	43.	0.0	0.0	0.0	0.0
8- 4-76	761772	0.0	37.	0.0	0.0	0.0	0.0
8- 5-76	761768	0.0	29.	0.0	0.0	0.0	0.0
8- 6-76	761766	0.0	50.	0.0	0.0	0.0	0.0

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NORTH DAKOTA STATE DEPARTMENT OF HEALTH

AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

Sample Site A-2

STATION NO. 350080001

		PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
	PARAMETER CODE	12602	11101	12403	12306	12202	11302
	METHOD CODE	91	91	92	93	91	91
	UNIT CODE	61	01	01	01	01	30
SAMPLE DATE	FILTER NO.		MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
7- 6-76	760561	0.0	196.	0.0	0.0	0.0	0.0
7- 7-76	760394	0.0	78.	0.0	0.0	0.0	0.0
7- 8-76	760341	0.0	314.	0.0	0.0	0.0	0.0
7- 9-76	760244	0.0	51.	0.0	0.0	0.0	0.0
7-12-76	760219	0.0	126.	0.0	0.0	0.0	0.0
7-13-76	760019	0.0	56.	0.0	0.0	0.0	0.0
7-14-76	761748	0.0	36.	0.0	0.0	0.0	0.0
7-15-76	761744	0.0	18.	0.0	0.0	0.0	0.0
7-16-76	761740	0.0	46.	0.0	0.0	0.0	0.0
7-19-76	761735	0.0	35.	0.0	0.0	0.0	0.0
7-20-76	761731	0.0	55.	0.0	0.0	0.0	0.0
7-21-76	761729	0.0	69.	0.0	0.0	0.0	0.0
7-22-76	761725	0.0	56.	0.0	0.0	0.0	0.0
7-23-76	761721	0.0	62.	0.0	0.0	0.0	0.0
7-26-76	761715	0.0	297.	0.0	0.0	0.0	0.0
7-27-76	761711	0.0	32.	0.0	0.0	0.0	0.0
7-28-76	761793	0.0	194.	0.0	0.0	0.0	0.0
7-29-76	761789	0.0	49.	0.0	0.0	0.0	0.0
7-30-76	761786	0.0	81.	0.0	0.0	0.0	0.0
8- 1-76	761780	0.0	113.	0.0	0.0	0.0	0.0
8- 3-76	761776	0.0	168.	0.0	0.0	0.0	0.0
8- 4-76	761773	0.0	63.	0.0	0.0	0.0	0.0
8- 5-76	761769	0.0	65.	0.0	0.0	0.0	0.0
8- 6-76	761808	0.0	66.	0.0	0.0	0.0	0.0

TABLE C-2 Continued

ML3020AA

NORTH DAKOTA STATE DEPARTMENT OF HEALTH

AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

Sample Site A-3

STATION NO. 350100001

SAMPLE DATE	FILTER NO.	PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
	PARAMETER CODE	12602	11101	12403	12306	12202	11302
	METHOD CODE	91	91	92	93	91	91
	UNIT CODE	61	01	01	01	01	30
			MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
7- 6-76	760567	0.0	101.	0.0	0.0	0.0	0.0
7- 7-76	760503	0.0	52.	0.0	0.0	0.0	0.0
7- 8-76	760362	0.0	98.	0.0	0.0	0.0	0.0
7- 9-76	760266	0.0	18.	0.0	0.0	0.0	0.0
7-12-76	760175	0.0	50.	0.0	0.0	0.0	0.0
7-13-76	760040	0.0	49.	0.0	0.0	0.0	0.0
7-14-76	761749	0.0	38.	0.0	0.0	0.0	0.0
7-15-76	761745	0.0	37.	0.0	0.0	0.0	0.0
7-16-76	761741	0.0	42.	0.0	0.0	0.0	0.0
7-19-76	761736	0.0	29.	0.0	0.0	0.0	0.0
7-20-76	761733	0.0	33.	0.0	0.0	0.0	0.0
7-21-76	761727	0.0	45.	0.0	0.0	0.0	0.0
7-22-76	761723	0.0	56.	0.0	0.0	0.0	0.0
7-23-76	761719	0.0	48.	0.0	0.0	0.0	0.0
7-26-76	761716	0.0	73.	0.0	0.0	0.0	0.0
7-27-76	761712	0.0	46.	0.0	0.0	0.0	0.0
7-28-76	761794	0.0	59.	0.0	0.0	0.0	0.0
7-29-76	761790	0.0	31.	0.0	0.0	0.0	0.0
7-30-76	761787	0.0	27.	0.0	0.0	0.0	0.0
8- 1-76	761781	0.0	60.	0.0	0.0	0.0	0.0
8- 3-76	761777	0.0	60.	0.0	0.0	0.0	0.0
8- 4-76	761774	0.0	31.	0.0	0.0	0.0	0.0
8- 5-76	761770	0.0	46.	0.0	0.0	0.0	0.0
8- 6-76	761807	0.0	97.	0.0	0.0	0.0	0.0

TABLE C-2 Continued

ML3020AA

NORTH DAKOTA STATE DEPARTMENT OF HEALTH

AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

Sample Site A-4

STATION NO. 350160001

SAMPLE DATE	FILTER NO.	PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
PARAMETER CODE		12602	11101	12403	12306	12202	11302
METHOD CODE		91	91	92	93	91	91
UNIT CODE		61	01	01	01	01	30
			MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
7- 6-76	760489	0.0	46.	0.0	0.0	0.0	0.0
7- 7-76	760436	0.0	34.	0.0	0.0	0.0	0.0
7- 8-76	760290	0.0	48.	0.0	0.0	0.0	0.0
7- 9-76	760132	0.0	27.	0.0	0.0	0.0	0.0
7-12-76	760156	0.0	40.	0.0	0.0	0.0	0.0
7-13-76	760053	0.0	49.	0.0	0.0	0.0	0.0
7-14-76	761746	0.0	22.	0.0	0.0	0.0	0.0
7-15-76	761742	0.0	33.	0.0	0.0	0.0	0.0
7-16-76	761738	0.0	25.	0.0	0.0	0.0	0.0
7-19-76	761737	0.0	49.	0.0	0.0	0.0	0.0
7-20-76	761732	0.0	27.	0.0	0.0	0.0	0.0
7-21-76	761726	0.0	42.	0.0	0.0	0.0	0.0
7-22-76	761722	0.0	34.	0.0	0.0	0.0	0.0
7-23-76	761719	0.0	50.	0.0	0.0	0.0	0.0
7-26-76	761717	0.0	25.	0.0	0.0	0.0	0.0
7-27-76	761713	0.0	32.	0.0	0.0	0.0	0.0
7-28-76	761795	0.0	21.	0.0	0.0	0.0	0.0
7-29-76	761791	0.0	32.	0.0	0.0	0.0	0.0
7-30-76	761783	0.0	34.	0.0	0.0	0.0	0.0
8- 1-76	761782	0.0	36.	0.0	0.0	0.0	0.0
8- 3-76	761778	0.0	79.	0.0	0.0	0.0	0.0
8- 4-76	761771	0.0	38.	0.0	0.0	0.0	0.0
8- 5-76	761767	0.0	50.	0.0	0.0	0.0	0.0
8- 6-76	761765	0.0	57.	0.0	0.0	0.0	0.0

TABLE C-2 Continued

ML3030AA

TABLE C-3: ANNUAL SUMMARY OF AIR QUALITY DATA OF THE NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site A-1

		POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
	ZONE 14	PARTICULATE (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	59.	34.	10.96	32.	1.36
350040001	5,200.650N	SULPHATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
	574.481E	NITRATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		FLUORIDES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		BETA RAD. (PCI/CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		PH	1	7/ 6/76	8/ 6/76	24	7.0	7.00	0.0	7.00	1.00

ML3030AA

ANNUAL SUMMARY OF AIR QUALITY DATA
OF THE
NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site A-2

		POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
		PARTICULATE (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	314.	97.	80.34	75.	2.04
350060001	5.197.000N	SULPHATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
	612.000E	NITRATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		FLUORIDES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		BETA RAD. (PCI/CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		PH	1	7/ 6/76	8/ 6/76	24	7.0	7.00	0.0	7.00	1.06

TABLE C-3 Continued

ML3036AA

ANNUAL SUMMARY OF AIR QUALITY DATA
OF THE
NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site A-3

		POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
	ZONE 14	PARTICULATE (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	101.	50.	20.35	46.	1.56
350100001	5,185,000N	SULPHATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
	363,830E	NITRATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		FLUORIDES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		BETA RAD. (PCI/CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		PH	1	7/ 6/76	8/ 6/76	24	7.0	7.00	0.0	7.00	1.00

TABLE C-3 Continued

ML3030AA

ANNUAL SUMMARY OF AIR QUALITY DATA

OF THE

NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site A-4

		POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
		PARTICULATE (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	79.	39.	13.23	37.	1.38
350160001	5.130.000N	SULPHATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
	623.000E	NITRATES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		FLUORIDES (MICRO G./CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		BETA RAD. (PCI/CU.M.)	1	7/ 6/76	8/ 6/76	24	0.00	0.00	0.00	0.01	1.01
		PH	1	7/ 6/76	8/ 6/76	24	7.0	7.00	0.0	7.00	1.00

TABLE C-3 Continued

TABLE C-4 NORTH DAKOTA STATE DEPARTMENT OF HEALTH

AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

Sample Site B-1

STATION NO. 350260001

		PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
PARAMETER CODE		12602	11101	12403	12306	12202	11302
METHOD CODE		91	91	92	93	91	91
UNIT CODE		61	01	01	01	01	30
SAMPLE DATE	FILTER NO.		MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
8-11-76	761764	0.0	246.	0.0	0.0	0.0	0.0
8-12-76	761811	0.0	141.	0.0	0.0	0.0	0.0
8-13-76	761815	0.0	59.	0.0	0.0	0.0	0.0
8-16-76	761819	0.0	129.	0.0	0.0	0.0	0.0
8-17-76	761824	0.0	183.	0.0	0.0	0.0	0.0
8-18-76	761828	0.0	188.	0.0	0.0	0.0	0.0
8-19-76	761832	0.0	116.	0.0	0.0	0.0	0.0
8-20-76	761836	0.0	44.	0.0	0.0	0.0	0.0
8-23-76	761840	0.0	572.	0.0	0.0	0.0	0.0
8-24-76	761905	0.0	74.	0.0	0.0	0.0	0.0
8-25-76	761900	0.0	141.	0.0	0.0	0.0	0.0
8-26-76	761896	0.0	234.	0.0	0.0	0.0	0.0
8-27-76	761891	0.0	78.	0.0	0.0	0.0	0.0
8-30-76	761888	0.0	140.	0.0	0.0	0.0	0.0
8-31-76	761887	0.0	201.	0.0	0.0	0.0	0.0
9- 1-76	761880	0.0	226.	0.0	0.0	0.0	0.0
9- 2-76	761876	0.0	261.	0.0	0.0	0.0	0.0
9- 3-76	761872	0.0	243.	0.0	0.0	0.0	0.0
9- 7-76	761868	0.0	63.	0.0	0.0	0.0	0.0
9- 8-76	761863	0.0	260.	0.0	0.0	0.0	0.0
9- 9-76	761859	0.0	377.	0.0	0.0	0.0	0.0
9-10-76	761855	0.0	239.	0.0	0.0	0.0	0.0

NORTH DAKOTA STATE DEPARTMENT OF HEALTH

AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

Sample Site B-2

STATION NO. 350300001

		PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
	PARAMETER CODE	12602	11101	12403	12306	12202	11302
	METHOD CODE	91	91	92	93	91	91
	UNIT CODE	61	01	01	01	01	30
SAMPLE DATE	FILTER NO.		MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
8-13-76	761816	0.0	31.	0.0	0.0	0.0	0.0
8-16-76	761821	0.0	96.	0.0	0.0	0.0	0.0
8-17-76	761825	0.0	105.	0.0	0.0	0.0	0.0
8-18-76	761829	0.0	136.	0.0	0.0	0.0	0.0
8-19-76	761833	0.0	75.	0.0	0.0	0.0	0.0
8-20-76	761837	0.0	59.	0.0	0.0	0.0	0.0
8-23-76	761908	0.0	119.	0.0	0.0	0.0	0.0
8-24-76	761904	0.0	55.	0.0	0.0	0.0	0.0
8-25-76	761899	0.0	44.	0.0	0.0	0.0	0.0
8-26-76	761895	0.0	112.	0.0	0.0	0.0	0.0
8-27-76	761889	0.0	212.	0.0	0.0	0.0	0.0
8-30-76	761884	0.0	60.	0.0	0.0	0.0	0.0
8-31-76	761883	0.0	50.	0.0	0.0	0.0	0.0
9- 1-76	761879	0.0	52.	0.0	0.0	0.0	0.0
9- 2-76	761875	0.0	122.	0.0	0.0	0.0	0.0
9- 3-76	761871	0.0	69.	0.0	0.0	0.0	0.0
9- 7-76	761867	0.0	32.	0.0	0.0	0.0	0.0
9- 8-76	761862	0.0	46.	0.0	0.0	0.0	0.0
9- 9-76	761858	0.0	43.	0.0	0.0	0.0	0.0
9-10-76	761854	0.0	44.	0.0	0.0	0.0	0.0

TABLE C-4 Continued

NORTH DAKOTA STATE DEPARTMENT OF HEALTH

AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

STATION NO. 350400001

Sample Site B-3

SAMPLE DATE	FILTER NO.	PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
	PARAMETER CODE	12602	11101	12403	12306	12202	11302
	METHOD CODE	91	91	92	93	91	91
	UNIT CODE	61	01	01	01	01	30
			MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
8-11-76	761806	0.0	37.	0.0	0.0	0.0	0.0
8-12-76	761813	0.0	34.	0.0	0.0	0.0	0.0
8-13-76	761817	0.0	29.	0.0	0.0	0.0	0.0
8-16-76	761822	0.0	83.	0.0	0.0	0.0	0.0
8-17-76	761826	0.0	81.	0.0	0.0	0.0	0.0
8-18-76	761830	0.0	86.	0.0	0.0	0.0	0.0
8-19-76	761834	0.0	47.	0.0	0.0	0.0	0.0
8-20-76	761838	0.0	48.	0.0	0.0	0.0	0.0
8-23-76	761907	0.0	91.	0.0	0.0	0.0	0.0
8-24-76	761903	0.0	43.	0.0	0.0	0.0	0.0
8-25-76	761898	0.0	25.	0.0	0.0	0.0	0.0
8-26-76	761894	0.0	60.	0.0	0.0	0.0	0.0
8-27-76	761890	0.0	125.	0.0	0.0	0.0	0.0
8-30-76	761885	0.0	52.	0.0	0.0	0.0	0.0
8-31-76	761882	0.0	39.	0.0	0.0	0.0	0.0
9- 1-76	761878	0.0	46.	0.0	0.0	0.0	0.0
9- 2-76	761874	0.0	86.	0.0	0.0	0.0	0.0
9- 3-76	761870	0.0	47.	0.0	0.0	0.0	0.0
9- 7-76	761866	0.0	25.	0.0	0.0	0.0	0.0
9- 8-76	761861	0.0	26.	0.0	0.0	0.0	0.0
9- 9-76	761857	0.0	29.	0.0	0.0	0.0	0.0
9-10-76	761853	0.0	34.	0.0	0.0	0.0	0.0

TABLE C-4 Continued

NORTH DAKOTA STATE DEPARTMENT OF HEALTH

AIR FILTER ANALYSIS FROM HI-VOLUME SAMPLER

STATION NO. 350560001

Sample Site B-4

SAMPLE DATE	FILTER NO.	PH	TOTAL PARTICULATES	SUSPENDED SULPHATES	SUSPENDED NITRATES	SUSPENDED FLUORIDES	BETA RADIATION
PARAMETER CODE		12602	11101	12403	12306	12202	11302
METHOD CODE		91	91	92	93	91	91
UNIT CODE		61	01	01	01	01	30
			MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	MICRO GRAMS / CU. M.	PCI / CU. M.
8-11-76	761810	0.0	128.	0.0	0.0	0.0	0.0
8-11-76	761809	0.0	76.	0.0	0.0	0.0	0.0
8-12-76	761814	0.0	66.	0.0	0.0	0.0	0.0
8-12-76	761812	0.0	57.	0.0	0.0	0.0	0.0
8-13-76	761818	0.0	74.	0.0	0.0	0.0	0.0
8-16-76	761823	0.0	236.	0.0	0.0	0.0	0.0
8-17-76	761827	0.0	66.	0.0	0.0	0.0	0.0
8-18-76	761831	0.0	141.	0.0	0.0	0.0	0.0
8-19-76	761835	0.0	124.	0.0	0.0	0.0	0.0
8-20-76	761839	0.0	77.	0.0	0.0	0.0	0.0
8-23-76	761906	0.0	163.	0.0	0.0	0.0	0.0
8-24-76	761902	0.0	31.	0.0	0.0	0.0	0.0
8-25-76	761897	0.0	43.	0.0	0.0	0.0	0.0
8-26-76	761893	0.0	119.	0.0	0.0	0.0	0.0
8-27-76	761892	0.0	104.	0.0	0.0	0.0	0.0
8-30-76	761886	0.0	97.	0.0	0.0	0.0	0.0
8-31-76	761881	0.0	146.	0.0	0.0	0.0	0.0
9- 1-76	761877	0.0	109.	0.0	0.0	0.0	0.0
9- 2-76	761873	0.0	146.	0.0	0.0	0.0	0.0
9- 3-76	761869	0.0	137.	0.0	0.0	0.0	0.0
9- 7-76	761865	0.0	24.	0.0	0.0	0.0	0.0
9- 8-76	761864	0.0	3.	0.0	0.0	0.0	0.0
9- 9-76	761860	0.0	260.	0.0	0.0	0.0	0.0
9-10-76	761856	0.0	250.	0.0	0.0	0.0	0.0

TABLE C-4 Continued

TABLE C-5 ANNUAL SUMMARY OF AIR QUALITY DATA
OF THE
NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site B-1

		POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
	ZONE 14	PARTICULATE (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	572.	191.	119.54	160.	1.90
350260001	5,328,750N	SULPHATES (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
	510,000E	NITRATES (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
		FLUORIDES (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
		BETA RAD. (PCI/CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
		PH	1	8/11/76	9/10/76	22	7.0	7.00	0.0	7.00	1.00

ANNUAL SUMMARY OF AIR QUALITY DATA
OF THE
NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site B-2

		POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
	ZONE 13	PARTICULATE (MICRO G./CU.M.)	1	8/13/76	9/10/76	20	212.	78.	45.06	68.	1.68
350300001	5.194.000N	SULPHATES (MICRO G./CU.M.)	1	8/13/76	9/10/76	20	0.00	0.00	0.00	0.01	1.01
	668.520E	NITRATES (MICRO G./CU.M.)	1	8/13/76	9/10/76	20	0.00	0.00	0.00	0.01	1.01
		FLUORIDES (MICRO G./CU.M.)	1	8/13/76	9/10/76	20	0.00	0.00	0.00	0.01	1.01
		BETA RAD. (PCI/CU.M.)	1	8/13/76	9/10/76	20	0.00	0.00	0.00	0.01	1.01
		PH	1	8/13/76	9/10/76	20	7.0	7.00	0.0	7.00	1.00

TABLE C-5 Continued

ML3030AA

ANNUAL SUMMARY OF AIR QUALITY DATA
OF THE
NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site B-3

		POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
	ZONE 14	PARTICULATE (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	125.	53.	27.12	48.	1.61
350400001	5.193.860N	SULPHATES (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
	668.880E	NITRATES (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
		FLUORIDES (MICRO G./CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
		BETA RAD. (PCI/CU.M.)	1	8/11/76	9/10/76	22	0.00	0.00	0.00	0.01	1.01
		PH	1	8/11/76	9/10/76	22	7.0	7.00	0.0	7.00	1.00

TABLE C-5 Continued

HL3030AA

ANNUAL SUMMARY OF AIR QUALITY DATA

OF THE

NORTH DAKOTA AIR QUALITY SAMPLING NETWORK

Sample Site B-4

	POLLUTANT	SAMPLING INTERVALS (MONTHS)	START DATE	END DATE	NUMBER OF SAMPLES	MAXIMUM 24 HRS.	ANNUAL ARITH. MEAN	STD. DEV.	ANNUAL GEO. MEAN	STD. GEO. DEV.
ZONE 13	PARTICULATE (MICRO G./CU.M.)	1	8/11/76	9/10/76	24	260.	112.	67.77	86.	2.49
350560001 5,139,000N	SULPHATES (MICRO G./CU.M.)	1	8/11/76	9/10/76	24	0.00	0.00	0.00	0.01	1.01
705,400E	NITRATES (MICRO G./CU.M.)	1	8/11/76	9/10/76	24	0.00	0.00	0.00	0.01	1.01
	FLUORIDES (MICRO G./CU.M.)	1	8/11/76	9/10/76	24	0.00	0.00	0.00	0.01	1.01
	BETA RAD. (PCI/CU.M.)	1	8/11/76	9/10/76	24	0.00	0.00	0.00	0.01	1.01
	PH	1	8/11/76	9/10/76	24	7.0	7.00	0.0	7.00	1.00

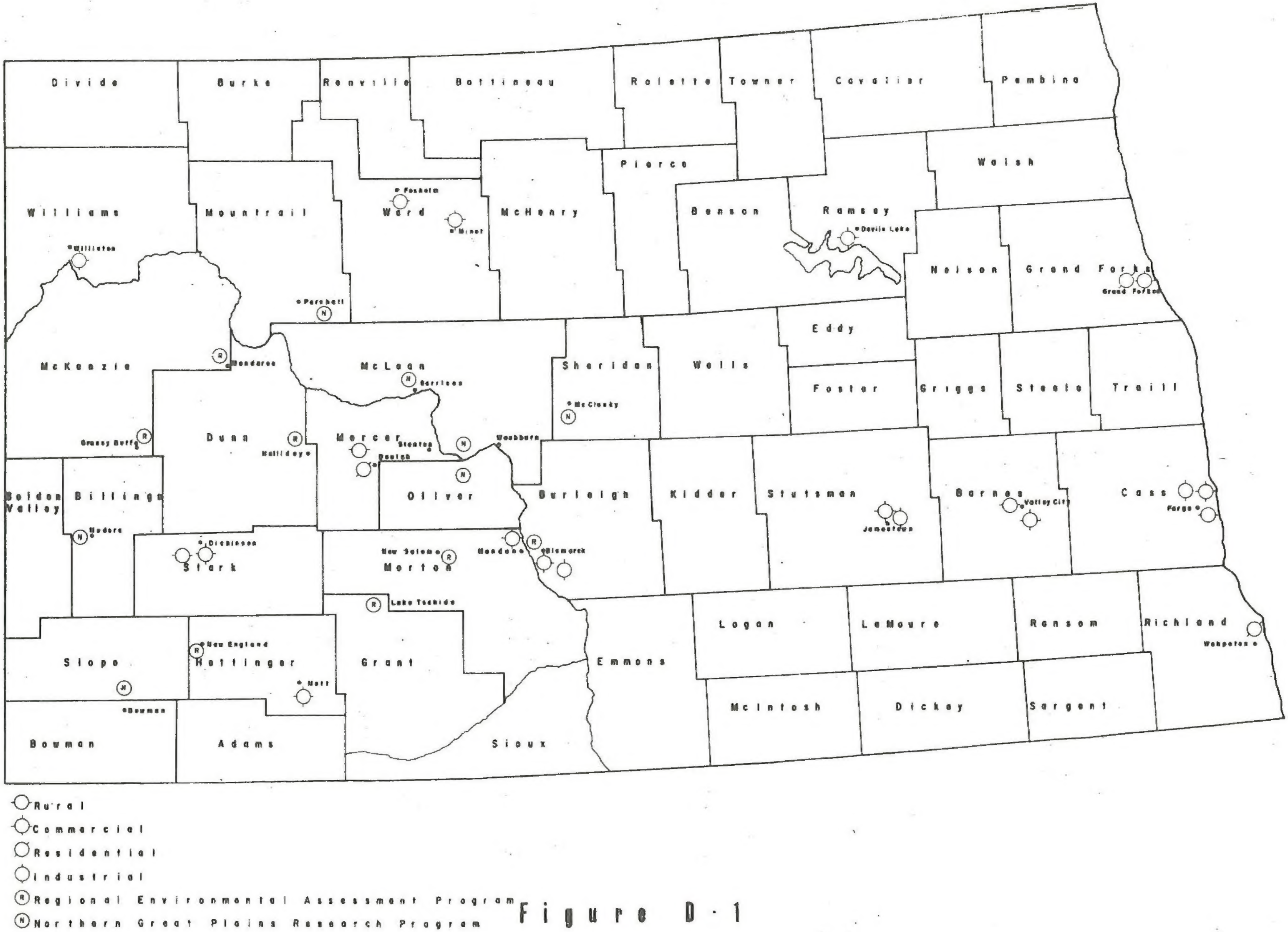
TABLE C-5 Continued

APPENDIX D.

North Dakota Air Quality Monitoring Network

AIR QUALITY MONITORING NETWORK

A portion of the baseline air quality data for the study was derived from existing information of the North Dakota Air Quality Monitoring Network. The following material in Appendix D presents information on locations of the State monitoring sites, the parameters and pollutants measured, the type of site, and the site operator.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Burke
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Mott
McIntosh
Dickey
Sargent
Bowman
Bowman
Adams
Sioux
Rural
Commercial
Residential
Industrial
Regional Environmental Assessment Program
Northern Great Plains Research Program

Figure D-1

Sampling Network

Sampling Site	SAROAD Number	Date Started	Pollutants Sampled	Type of Site
Beulah Zip: 58523	350760001	April 1974	Hi-Volume, Sulfation Rate, SO_2, NO_2	Residential
Beulah Zip: 58523	350760002	July 1974	Hi-Volume, Sulfation Rate, SO_2, NO_2	Rural
Bismarck Zip: 58501	350100001	January 1958	Hi-Volume, Sulfation Rate, SO_2, NO_2, Cascade, Dustfall, Coefficient of Haze	Commercial
Bismarck Zip: 58501	350100002	January 1975	Hi-Volume, Sulfation Rate, SO_2, NO_2	Industrial
Bismarck Zip: 58501 (REAP)	350200001	December 1976	Hi-Volume, Sulfation Rate SO_2, NO_2 (Bubbler) SO_2, NO_2 (continous) cascade Impactor Continuous Oxident Met.[1], pH [2]	Rural
Bowman Zip: 58623 (NGPRP)	350160001	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate	Rural
Devils Lake Zip: 58301 12 day	350260001	January 1970	Hi-Volume, Sulfation Rate 12 day	Commercial
Dickinson Zip: 58601 12 day	35030001	January 1970	Hi-Volume, Sulfation Rate	Commercial

[1] Met= Climatronics Meteorological Station

[2] pH= Precipitation Measurement for pH Determination

Sampling Site	SAROAD Number	Date Started	Pollutants Sampled	Type of Site
Dickinson Zip: 58601	351140001	December 1975	Hi-Volume, Sulfation Rate, SO_2, NO_2	Rural
Fargo Zip: 58102	350400001	January 1964	Hi-Volume, Sulfation Rate, SO_2, NO_2, Coefficient of Haze	Commercial
Fargo Zip: 58102	350400002	February 1971	Hi-Volume, Sulfation Rate	Industrial
Fargo Zip: 58102	350220001	February 1971	Hi-Volume, Sulfation Rate	Rural
Garrison Zip: 58540 (NGPRP)	350720001	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate, Membrane	Rural
Grand Forks Zip: 58201 12 day	350480001	January 1970	Hi-Volume, Sulfation Rate 12 day	Commercial
Grand Forks Zip: 58201	350480002	January 1972	Hi-Volume, Sulfation Rate	Residential
Grassy Butte Zip: 58634 (REAP)	350700001	September 1976	Hi-Volume, Sulfation Rate, SO_2, NO_2, Met, pH	Rural
Halliday Zip: 58636 (REAP)	350340002	October 1976	Hi-Volume, Sulfation Rate SO_2, NO_2, Met, pH	Rural
Jamestown Zip: 58401 12 day	351180001	January 1972	Hi-Volume, Sulfation Rate 12 day	Rural

Sampling Site	SAROAD Number	Date Started	Pollutants Sampled	Type of Site
Jamestown Zip: 58401 12 day	350580001	January 1974	Hi-Volume, Sulfation Rate 12 day	Commercial
Lake Tschida Zip: 58631 (REAP)	350520001	September 1976	Hi-Volume, Sulfation Rate SO_2, NO_2, Met, pH	Rural
Mandan Zip: 58554	350740001	October 1970	Hi-Volume, Sulfation Rate, SO_2, NO_2	Commercial
Mandaree Zip: 58757 (REAP)	350340001	August 1976	Hi-Volume, Sulfation Rate, pH	Rural
McClusky Zip: 58463 (NGPRP)	351060001(014) *351060002(013) *Redundant Sampler	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate, Met	Rural
Medora Zip: 58645 (NGPRP)	350080001	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate, Met	Rural
Minot Zip: 58701 12 day	350780001	April 1967	Hi-Volume, Sulfation Rate 12 day	Commercial
Mott Zip: 58646 (NGPRP)	350560001	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate, SO_2, NO_2, Met	Commercial
New England Zip: 58647 (REAP)	350560002	August 1976	Hi-Volume, Sulfation Rate, pH	Rural

Sampling Site	SAROAD Number	Date Started	Pollutants Sampled	Type of Site
New Salem Zip: 58563 (REAP)	350800001	August 1976	Hi-Volume Sulfation Rate, pH	Rural
Parshall Zip: 58770 (NGPRP)	350820001	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate, Met	Rural
Stanton Zip: 58571 (NGPRP)	350860001	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate, Met SO_2, NO_2, (Bubbler) SO_2, NO_2 Continuous, Cascade Impactor, Continuous Oxidant	Rural
Upper Souris National Wildlife Refuge Foxholm Zip: 58738	351300001	January 1958	Hi-Volume, Sulfation Rate	Rural
Valley City Zip: 58072 12 day	351240001	January 1972	Hi-Volume, Sulfation Rate 12 day	Commercial
Valley City Zip: 58072 12 day	350040002	January 1972	Hi-Volume, Sulfation Rate 12 day	Rural
Wahpeton Zip: 58075 12 day	351260001	October 1970	Hi-Volume, Sulfation Rate 12 day	Residential

Sampling Site	SAROAD Number	Date Started	Pollutants Sampled	Type of Site
Washburn Zip: 58577 (NGPRP)	350720002	Fed: Sept. 1974 State: Sept. 1975	Hi-Volume, Sulfation Rate, SO_2, NO_2	Rural
Williston Zip: 58801 12 day	351360001	May 1970	Hi-Volume, Sulfation Rate 12 day	Commercial

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